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CHARACTERISTICS OF THE REGION OF INTERACTION BETWEEN THE INTERPLANETARY PLASMA AND THE GEOMAGNETIC FIELD: PIONEER 5

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Measurements of the magnetic fields in the distant geomagnetic cavity and in the region of interaction between the solar wind and the magnetosphere are described. These measurements were obtained on 11 March, 1960 with instruments aboard the interplanetary probe, Pioneer 5, in the region between 5.2 and 15.4 Re and between 1500 and 1700 local time. The observations obtained between 5.2 and 15.4 Re are found to be consistent with a geomagnetic boundary region which exhibits an enhanced field just inside the geomagnetic cavity, and beyond the cavity, a region of disordered fields in which both the mean field and the amplitude of the field variations decrease with increasing geocentric distance. Evidence for the extension of an interaction region to at least 25.6 Re along the spacecraft trajectory on the day of the launch is presented. The observations are compared to two models for this interaction region.

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Introduction

On March 11 and 12, 1960, observations of the magnetic fields in the vicinity of the boundary between interplanetary space and the geomagnetic field were obtained with a magnetometer aboard the interplanetary space probe, Pioneer 5. This article is intended to supplement a preliminary report (Coleman, Sonett, Judge, and Smith, 1960) on these measurements. Recently considerable discussion in the literature has concerned models of this boundary or interaction region which include a collision-free, standing shock wave on the sunward side of this interface. Such a shock wave is considered a likely result of the interaction of a supersonic solar wind with the earth's magnetosphere. Axford (1962), for example, has suggested that "the magnetic 'boundary' observed at a distance of 13-14 Re (1 Re radius of earth) during the flights of Pioneers 1 and 5, was simply the shock wave and not the termination of the geomagnetic field as had been suggested." In the present paper it is intended to describe, in somewhat greater detail the field measurements from the first days of the flight of Pioneer 5, to compare them with some of the observations obtained in this region by other experimenters, and to discuss these empirical results in terms of various models of this interaction region at the limits of the magnetosphere.

In the course of the discussion it will become apparent that the greatest difficulty encountered in our attempt to reconcile these measurements with the shock wave model is associated with the data obtained at 22.0 Re and 25.4 Re. Along the trajectory of Pioneer 5, the boundary between the geomagnetic field and the interface region, a region characterized by disordered fields, was located somewhere between 8.5 and 10.5 Re. There is some indication of the presence of a second boundary of a different type between 15.1 and 22.0 Re. In most of the more recently presented shock wave models, the shock front is located approximately in this range of distances from the earth at the local time corresponding to the position of Pioneer 5. Upstream from the front, a supersonic solar wind, unaffected by any phenomena associated with the magnetosphere is expected. However, the data from the Pioneer 5 flight provided some evidence for geocentric effects beyond this expected range of shock front locations and, infact, beyond 25 Re. This evidence, obtained from a comparison of the observations at 22 and 25 Re with those at geocentric distances beyond 26 Re, will also be described.

Trajectory and Orientation Data

Pioneer 5 was launched from Cape Canaveral, Florida at 1300 GMT on 11 March, 1960. The essential features of the trajectory of the spacecraft are shown in Figures 1 and 2. In the former figure, the trajectory is shown projected upon the XY-plane (the plane of the earth's equator) and the YZ-plane of the rectangular inertial coordinate system, centered at earth's center, with the X-axis positive toward the vernal equinox of date and the Z-axis positive toward the north pole of the earth's axis. Note that the angle between the projections of the XY-plane of the earth-sun vector and the earth-spacecraft vector during the more distant position of the near-earth trajectory is almost 70°. Thus, the local time of the spacecraft position during most of this portion of the flight was about 16:40. In the period during which Pioneer 5 traversed the boundary region of the geomagnetic field, the sun-earth-spacecraft angle ranged from 50° to this 70° limit. Portions of the trajectory over which the spacecraft transmitted information are indicated in Figure 1 by the heavier sections of the trajectory projections. In Figure 2, the geomagnetic latitude is plotted versus geocentric range for the near-earth portion of the Pioneer 5 trajectory.

The spin axis of Pioneer 5 lay nearly parallel to the ecliptic plane, i.e., at an angle of about 88° with the normal to the ecliptic. Initially, the angle between the spin axis and the sun-earth line was about 23°.

Magnetometer and Telemetry Systems

The sensing element of the magnetometer aboard Pioneer 5 was a multi-turn coil, fixed in the spacecraft. The spacecraft was stabilized by a rotation about its axis of figure at a rate of 2.40 revolutions per second. The resulting rotation of the coil in a constant ambient magnetic field would generate a sinusoidal e.m.f., the amplitude of which would be proportional to the magnetic field component, transverse to the axis of rotation of the spacecraft. The signal from the coil was amplified and rectified. The amplifier contained an automatic gain control which provided a reduced sensitivity with increased magnitude of the measured component of the field. The low-pass response, to field variations, at the output of the instrument exhibited a half-power point at about 0.23 cps. The mean field equivalent noise level was below 1 γ (1 $\gamma = 10^{-5}$ gauss). The rms field equivalent noise amplitude was less than 0.2 γ. The magnetometer, including the amplifiers, and other associated electronic circuitry, has been described in detail by Judge, McLeod, and Sims (1960).

The voltage level of the rectified signal from the magnetometer was converted into numbers between 1 and 64 for transmission by the digital telemetry system. The ranges of field component values corresponding to Channel-Numbers 27-39 are shown on the right-hand sides of the plots of Pioneer 5 data in Figure 4.

In order to more efficiently use the transmitted signal, information was transmitted at three rates, 64, 8, and 1 bits per second, depending, for a particular transmission, upon the distance of the spacecraft from the earth and upon the size of the receiving antenna at the receiving station which had the spacecraft in view. Corresponding to these data rates, the sampling rates for the rectified magnetometer output voltage were one sample per 1.5, 12, and 96 seconds, respectively.

The telemetry system aboard Pioneer 5 provided useful data from the magnetometer between March 11 and May 18, 1960. During this 68-day interval, approximately 295 periods of data transmissions were recorded. These periods average 20 minutes. Table 1 shows the distribution of the transmission periods at various rates over the period of flight.

Observations to 26 Re

The larger-scale features of the observations obtained in the vicinity of the geomagnetic field boundary during the Pioneer 5 flight are shown in Figure 3. The data plotted in the figure consist of averages, over 40 measurements, of field measurements which were taken every 1.5 seconds, i.e., averages over one-minute. Note that flags are used to represent the averages obtained during Transmissions 2 and 3. In each case, the size of the flag corresponds to the range of field values covered by a single channel. The flags are used rather than points when the corresponding channel number was the only one recorded during a particular one-minute.

Also, in Figure 3, the observed values of the measured component of the field are compared to those computed from the eccentric dipole model of the geomagnetic field which has been described by Vestine (1953) and which is based upon a spherical harmonic expansion of degree three calculated for the surface field by Vestine and Lange. From 5.4 Re to at least 6.1 Re, the measured field component was somewhat less than that expected from Vestine's model. This effect which could be the result of a slightly distorted field at these distances and locations relative to the sub-solar point, has been discussed in a previous report (Smith, Coleman, Judge, and Sonett, 1960).

The data shown in Figure 3 indicate that, between 6.1 and 7.8 Re, the measured component became greater than the values predicted and remained greater than expected to at least 15.1 Re. Since data were not transmitted continuously, this situation is inferred from the fact that the measured values were greater than expected throughout the 3rd, 4th, and 5th transmissions of data from the spacecraft.

During Transmissions 2 and 3, as a result of the operation of the automatic gain control, the sensitivity of the magnetometer was considerably reduced. The effect is apparent from the size of the flags in Figure 3 and from the field ranges corresponding to the various channels shown in Figure 4. However, from the manner in which the transitions occurred between Channels 36, 37, 38, and 39 during Transmission 2 and between Channels 33 and 34 during Transmission 3, an approximate upper limit may be placed upon the peak-to-peak magnitude of fluctuations which could have escaped definite detection during these periods of observation. This limit is about 17 γ. Thus, even relatively large-amplitude variations in the magnetic field, e.g., variations of the type frequently observed at such distances during the flight of Explorer VI (Judge and Coleman, 1962), could have escaped observation. Of course, comparatively small-amplitude field variations of the type observed during the flight of Pioneer I in this range of geocentric distances (Sonett, Sims and Abrams, 1963) would not have been detected by the magnetometer aboard Pioneer 5.

The results from Pioneer 5 provided the first measurement of the radial dimension of the region of interaction between the magnetosphere and the interplanetary medium, i.e., the region of fluctuating magnetic fields beyond the proper magnetosphere. Since the details of the observed fluctuations are obscured by the scale of time used in Figure 3, portions of Transmissions 3-8 have been plotted on an expanded timescale in Figure 4. From the results shown in Figure 4, it appears that the observed disordered fields extended from a distance somewhere between 8.5 and 10.5 Re to a distance between 25.4 and 29.6 Re along the trajectory of Pioneer 5, at least on this particular day.

First, considering the mean values, denoted by m, as well as the rms deviation from the means of the measured fields, denoted by σ, assume for the moment that these properties of the measured fields exhibit the effects of dependence upon distance from the earth, rather than the effects of transient phenomena. Then the appearance of the data shown in Figures 3 and 4 suggests that the region of disordered fields may be divided into two sub-regions, one in which the measured average value of the field decreases with distance r from the earth, and a second, more distant subregion in which this average value is nearly independent of r. The radial dependence of the averages is more readily observed on the logarithmic scale shown in Figure 5. In the nearer of the subregions, the field decreases approximately in proportion to $r^{-1.7}$. Note that this dependence upon r also appears to describe the measured field between 8.0 Re and the inner boundary of the interaction region. The deviation from the $r^{-1.7}$ dependence or, more specifically, the absence of any detectable radial dependence, exhibited by the measured averages from Transmissions 6 and 7 provide indirect evidence for the existence of a boundary of some sort between 15.3 and 21.8 Re dividing the region of disordered fields into the two sub-regions just mentioned.

Additional evidence for this division is provided by a study of the amplitudes of the fluctuations observed in this region which also exhibit a marked decrease between Transmissions 4 and 7. This decrease is apparent from the graph of the mean square deviations calculated for the field variations recorded during each transmission. This graph is shown also in Figure 5. The difference in the total power estimated for the records of Transmissions 4 and 5 would be consistent with a dependence upon radial distance proportional to $r^{-3.8}$. The difference between the values of the total power obtained for the records of Transmissions 6 and 7 is very small indicating a change in the radial dependence of this parameter between Transmissions 5 and 6. This change in the radial dependence of the fluctuation amplitudes provides additional indirect evidence for a boundary between 15.3 and 21.8 Re. Estimates of the spectra of the observed fluctuations obtained from the records of Transmissions 4, 5, 6, 7, 8, and 9 are plotted in Figure 6. Linear trends were removed from the recorded data before the spectral estimates were calculated, but no correction for the transfer function of the magnetometer was included. These results will be discussed in more detail in subsequent paragraphs.

It is possible that a boundary of some type was also crossed at about 14 Re by Pioneer 1. The evidence for such an event consists of a relatively abrupt decrease in the mean value of the measured field observed at about 14 Re on the trajectory of Pioneer 1. This observation has been described by Sonett, Judge, Sims, Kelso (1960); Sonett and Abrams (1963); and Sonett (1963); and has been attributed by the experimenters to the traversal of the outer boundary of the geomagnetic field or of the region of interaction between the geomagnetic field and the interplanetary medium. Such a boundary might well have been traversed by Pioneer 5 during the period, between Transmissions 5 and 6, while the transmitter was off, thus accounting for the abrupt decreases in the mean field and mean square deviation from Transmission 5 to Transmission 6.

Pioneer 1 provided boundary measurements at about noon, local time, while Pioneer 5 transversed the region of interest between approximately 15:40 and 16:40, local time, or between 50° and 70° on the afternoon side of the earth-sun line. Pioneer 1 may have crossed a boundary at about 14 Re. Pioneer 5 may have crossed one between 15.3 and 21.8 Re. If these two sets of observations indeed apply to a boundary which is characteristic of the magnetosphere, then the results would be consistent with the presence of a boundary which exhibits one property of the gross geometry expected of the shock front, i.e., the property that the distances from the earth of locations along the boundary or front increase with increasing distance from the subsolar point, or, more accurately, from the stagnation point. In fact, most simple models indicate a roughly hyperbolic surface of revolution as the most likely approximation for the shape of the shock front if the magnetosphere is assumed to be spherical in the subsolar hemisphere. From more realistic models of the magnetosphere, e.g., that of Beard (1960), some variation of this shape are expected. In theory, however, the most significant differences associated with these non-spherical shapes is an increase in the standoff distance of the shock wave. Spreiter and Jones (1963), for example, have described a shock wave boundary for a solar wind with a velocity of 600 km/sec, a proton density of 2.5 cm^{-3}, and a magnetic field of 5 γ. A trace of this boundary is shown in Figure 7. The nose of this shock wave is located at about 14.0 Re. Assuming approximate rotational symmetry about the line, through earth's center and parallel to the velocity of the solar wind relative to the earth, the trace is approximately that in the plane of the trajectory of Pioneer 5. The trajectory is also plotted in the figure. Note that the data from Pioneer 5 which suggests that there existed a boundary between 15.3 and

21.8 Re are consistent with this model. This consistency has been discussed by Spreiter and Jones. However, the fluctuations observed beyond 21.8 Re, to at least 25.5 Re, appear to be inconsistent with the straightforward interpretation of this boundary as a shock front of the type discussed in the model. This inconsistency will be discussed further in subsequent paragraphs.

The salient properties of the magnetic fields measured along the trajectory of Pioneer 5 in the vicinity of the boundary of the magnetosphere may be summarized as follows:

1) Beyond about 6 Re, the measured component of the geomagnetic field exceeded the expected values. The difference between the two increased with increasing radial distance from the earth. The measured field decreased approximately as $r^{-1.7}$.

2) While the transmitter was off, between Transmissions 3 and 4, a boundary between the comparatively regular, although somewhat distorted geomagnetic field and a region characterized by disordered fields was evidently traversed.

2) (Continued) According to this observation the boundary was located somewhere between 8.6 and 10.4 Re.

3) To at least 15.4 Re, in the region of disordered fields, the mean value of the measured component exhibits the $r^{-1.7}$ dependence and the total power in these fluctuations evidently decreases as $r^{-3.2}$.

4) While the transmitter was off, between Transmissions 5 and 6, a second boundary of some sort was evidently traversed. Beyond this boundary, which would have been located between 15.4 and 21.8 Re disordered fields of the same qualitative properties, but with fluctuations of smaller amplitudes about a mean value of the measured component of approximately 4.6 γ were observed. This situation evidently persisted to 25.6 Re, which was the radial distance from the earth of Pioneer 5 at the end of Transmission 7. No appreciable dependence upon r was exhibited by the mean values during Transmissions 6, 7, and 8. There is a slight decrease in the fluctuations observed during Transmission 7 relative to those observed during Transmission 6.

5) At the beginning of Transmission 8, at 29.7 Re, the field had steadied about an average value of 4.9 γ at which value it held without detectable fluctuation throughout the transmission period. During Transmission 9, an average value of 3.6 γ was recorded while the field exhibited only relatively long period fluctuations of small amplitude.

Subsequent measurements obtained with Explorer 12, by Cahill and Amazeen (1963), leave little doubt that the results described in Items 1 and 2 are typical for the fields in the vicinity of the boundary region of the geomagnetic field on the subsolar surface of the magnetosphere. The earth satellite, Explorer 12 traversed the boundary many times during its useful life of several months. Its orbit provided a period of 26 hours and 25 minutes and an apogee of 13 Re.

From Item 3, note that the inner subregion of disordered fields extended to at least 15.4 Re at the time of the Pioneer 5 observations. A region of disordered fields has been detected beyond the magnetosphere in all the observations reported to date. This region extended to at least 13-14 Re at the time of the

Pioneer 1 flight. (Sonett, Judge, Sims, and Kelso, 1960). It is not certain whether the outer extremity of the disordered region was traversed at about 14 Re on this flight or whether a boundary between subregions of the type just mentioned might have been encountered. Explorer 12 data [Cahill and Amazeen, 1963; Freeman, Van Allen, and Cahill, 1963] indicate that the region of fluctuating fields evidently always extended to at least satellite apogee, 13 Re, on the subsolar side of the magnetosphere, since no outer limit was observed.

The confirmation by Explorer 12 data of the Pioneer 5 results pertaining to the region within about 13 Re leaves as the subject for a more speculative interpretation the observations obtained beyond 13 Re with Pioneer 5. In Item 4, the suggestion was made to the effect that the region of disordered fields was divided into two subregions by a boundary between 15.4 and 21.8 Re. The indirect evidence which supports this suggestion has been discussed previously in this section.

However, whether or not such a subdivision did exist, the question remains as to the source for the relatively short period fluctuations in the measured field component which were detected near 22 and 25.4 Re. That is, were these fluctuations a solar-interplanetary phenomenon or were they the result of the interaction of the interplanetary medium and the magnetosphere even at these extreme geocentric ranges?

The evidence from Pioneer 5 indicates that the latter possibility is the more likely. This evidence was obtained from a comparison of the characteristics of the measured field observed during Transmissions 6 and 7 (which occurred at approximately 22 and 25.4 Re, respectively) with the characteristics of fields observed in interplanetary space during subsequent transmissions of data. This comparison is the subject of the next section.

Observations beyond 26 Re.

The records for Transmissions 6 and 7 were compared to the records of eighty-three subsequent periods of data transmissions. These records were obtained at a data rate of either 64 or 8 bits-per-second (bps). The records for the 203 periods during which data were transmitted at 1 bps were not examined, since the usual transmission period did not permit the accumulation of numbers of field measurements great enough to provide values of the various quantities of interest with sufficient statistical accuracy.

The eighty-three transmission periods which were studied averaged 23 minutes in length. They were obtained between 11 March and 16 April, 1960. Thus, on the average, the fields were measured for about one hour per day, during this period, at the 64 or 8 bps data rate. The distribution of these eighty-three periods, as well as others of their characteristics are shown in Table 2.

As the first step in the comparison of these records with those from Transmissions 6 and 7, the mean value of the measured component of the magnetic field, m, and the root-mean-square (rms) deviation from the mean, σ, were computed from each of the records.

The values of m and σ from Transmissions 6 and 7 which provided data at the 64 bps rate were compared directly with the values obtained from subsequent transmissions of data at the 64 bps rate. However, in order to compare measurements obtained during Transmissions 6 and 7 with measurements obtained from data transmitted at the 8 bps rate, it was necessary to simulate the effects of the lower rate upon the data obtained during Transmissions 6 and 7. As a result of this simulation process 8 sets of the 'simulated' 8 bps data were obtained from each of Transmissions 6 and 7. The simulation process was simply the selection of every 8th datum point in the records obtained at 64 bps to form sets of simulated 8 bps data. Thus, sixteen sets of simulated 8 bps data, eight sets from each of Transmissions 6 and 7, were obtained for comparison with the actual 8 bps data taken in interplanetary space.

This procedure is considered valid, since the analog signal presented by the magnetometer to the analog-to-digital converter aboard the spacecraft was not affected by the change in data rate, nor was the actual conversion process. Only the rate of magnetometer readout was changed. Evidence for the validity of this procedure is found in the reproducibility, over 16 sets of simulated data, of the values of m and σ.

In several cases, the comparison of the results from Transmissions 6 and 7, obtained at either 64 bps or simulated 8 bps, with those from subsequent transmissions at these data rates was straightforward. However, one complication arose because the binary element corresponding to the least significant digit of the binary element corresponding to the binary coded digital readout of the analog-to-digital converter failed to operate properly during some of the transmission periods. In the failure mode, this unit always read "one". Thus, only odd numbers were transmitted during the intermittent periods in which this failure occurred so that, for example, the actual values 24 and 25 would be both transmitted as 25's. This failure effectively reduced the magnetometer sensitivity by a factor of about two. The factor varies as a result of the characteristics of the magnetometer's automatic gain control. Any occurrence of this type of failure was easily detected because telemetered voltages pertaining to the performance of certain spacecraft subsystems changed monotonically during each transmission period. Thus, during a period of the binary failure, the data corresponding to such voltages would show monotonic changes through adjacent odd numbers. In order to permit comparisons between data from Transmissions 6 and 7 and data from other transmissions during which the failure was observed, the failure was simulated in the former data, obtained at either 64 or simulated 8 bps, by simply changing all recorded even numbers to the next highest number. The values of m and σ obtained from the data of Transmissions 6 and 7 by these processes are listed in Table 3. Note that the results from both actual and simulated data, are listed in four catagories according to the data rate and the state of the intermittant binary element of the analog-to-digital converter. Specifically, the catagories are: 64 bps-Normal, 64 bps-Binary Inoperative, 8 bps Normal and 8 bps-Binary Inoperative.

Thus, the comparisons of the values of m and σ were made in four catagories as follows:

1) Values for normal transmissions at 64 bps were compared directly to values for Transmissions 6 and 7; Table 4.

2) Values for transmissions at 64 bps during which the binary failure occurred were compared to values obtained from Transmissions 6 and 7 by simulating the effects of the binary failure; Table 5.

3) Values for normal transmission at 8 bps were compared to values obtained from Transmissions 6 and 7 by simulating the 8 bps data rate; Table 6.

4) Values for transmissions at 8 bps during which the binary failure occurred were compared to values obtained from Transmissions 6 and 7 by simulating both the 8 bps data rate and the binary failure; Table 7.

Because of the automatic gain control, which effectively reduced the sensitivity of the magnetometer as the measured field component increased in value, the comparison being considered is useful only when the mean value of the measured component recorded during a particular transmission was less than about 7.4 or 6.1 γ depending, respectively, upon whether or not the faulty binary was operating properly. In a field much greater than this value, the magnetometer sensitivity would have been reduced so that variations with rms values of 2 γ or so could have escaped detection. This problem will be discussed in greater detail below.

The inability to compare periods during which the mean values of the measured component were realtively high may not be a severe drawback, however, because the mean value of this component appears to be a fairly accurate indicator of the gross state of the interplanetary medium. Studies of the measurements of the interplanetary field from Pioneer 5 by Coleman, Sonett, and Davis (1961); Greenstadt (1961); and

Greenstadt and Moreton (1962) have demonstrated this relationship by the correlations between these measurements and various solar-terrestrial phenomena. Thus, the occurrence of fluctuations of the type observed during Transmissions 6 and 7, if these fluctuations were an interplanetary phenomenon, would be more likely when the conditions in interplanetary space were the same as the conditions during these transmission periods, and these conditions would, in turn, have been more likely when the mean value of the interplanetary field was about the same as that recorded during these periods. The portion of 11 and 12 March of interest here included the recovery phase of a gradual commencement geomagnetic storm of moderate intensity which began between 0400 and 1000 GMT on 11 March and ended between 2200 on 11 March and 0100 on 12 March. (Lincoln, 1960). Due to this storm, 11 March was one of the five disturbed days of the month. Values of the Kp index assigned to the consecutive 3-hour periods which included the periods of Transmissions 3-9 from Pioneer 5 are: 5- for Transmissions 3 and 4; 4+ for Transmission 5; 3o for Transmissions 6 and 7; 2+ for Transmission 8; and 2o for transmission 9.

Thus, the existence, during Transmissions 6, 7, and 8 of an interplanetary field intensity somewhat greater than the subsequently observed "quiet-time" value is consistent with the occurrence of some geomagnetic activity during the period of the observations. It should be mentioned that the mean field strength, $m = 3.6\ \gamma$, measured during Transmission 9, was closer to the usual quiet-time value of about $2.7\ \gamma$. This transmission occurred between 0500 and 0520 GMT on 12 March at which time the spacecraft was some 220,000 Km. from the earth and the geomagnetic activity had decreased somewhat so that the assigned value of Kp for the period was 2_o as indicated above. Evidently then, conditions in interplanetary space near the earth during Transmissions 6 and 7 might be characterized, according to the Kp indices, as only slightly disturbed.

The values of m and σ for the five periods of normal data transmission at 64 bps, subsequent to Transmissions 6 and 7 are contained in Table 4. All five records showed values of σ which were samller by factors of at least 2 than those for transmissions 6 and 7, and values of $m \leq 4.8\ \gamma$. Such values indicate the absence of fluctuations of the magnitudes detected during Periods 6 and 7. The different properties of the field variations recorded during Transmissions subsequent to 6 and 7 are even more evident in estimates of the power spectra which have been calculated from the records. A comparison of the spectra of Transmissions 6 and 7 with those of Transmissions 8 and 9 may be made in Figure 6. The latter pair exhibit spectra which are typical of those obtained for the other three transmissions during which normal operation at the 64 bps rate was obtained. Note the local minima at .06 cps in the spectra from the records of Transmissions 8 and 9 and the local maxima at this same frequency in the spectra from Transmissions 6 and 7. The differences in the total power are again apparent, as they were from the values of σ. Thus, no evidence for the recurrence of field fluctuations such as those recorded during Transmissions 6 and 7 can be found in the subsequently obtained normal 64 bps data.

A similar comparison was made between the values of m and σ for the records obtained at 64 bps during the twelve transmission periods in which the binary failure was in evidence. In these cases the values of m and σ were compared with values of the same quantities calculated from the data of Transmissions 6 and 7 in which the binary failure had been simulated. The comparison may be made from Table 5.

In the following, the asterisk * will indicate channel numbers recorded when the binary was inoperative. Under this condition Channel 25* of the digital readout covered the range of field values from 2.4 to 5.0 γ and Channel 27* covered the range from 5.0 to 12.0 γ, i.e., since only odd numbers were recorded, Channel 25* covered the normal range of Channels 24 and 25 while Channel 27* covered the normal range of Channels 26 and 27. With the binary inoperative, each reading of Channel 25* was weighted at 3.7 γ and each reading of Channel 27* was weighted at 8.5 γ. Thus, a calculated value of $m \leq 6.1$ γ would indicate that half or more of the observations contained in a record were in Channel 25* or below. With $m \leq 6.1$ γ, the maximum rms field variation which could escape detection is $\sigma = (6.1 - 5.0)/\sqrt{2} = 0.78$ γ. Because of the weighting, a value of σ slightly greater than this threshold value could have a calculated value as large as $(6.1 - 3.7)/\sqrt{2} = 1.7$ γ. More generally, for values of $m \leq 6.1$, the maximum rms field variation which could escape detection is $\sigma = (m - 3.7)/\sqrt{2}$.

As a result of the situation outlined above, it was assumed that field variations of the type observed during T[illegible]ions 6 and 7 were not observed during any of the twelve periods from which the records exhibited $m \leq 6.1$ γ and

$\sigma \leq 1.3\ \gamma$. The value of m was selected for the reasons just mentioned and the value of σ was selected because it is less than half the smaller value of σ calculated for Transmissions 6 and 7. Under these criteria, four of the twelve records were removed from further consideration.

As the next step in the examination of the remaining eight records, estimates of the power spectra were calculated. These estimates were compared to similar estimates calculated from the records of Transmissions 6 and 7 in which the binary failure had been simulated. Of the eight records presently under discussion, five exhibited values of $m \leq 6.1\ \gamma$ and the other three exhibited values of 7.2, 7.6, and 8.5 γ. The spectra estimated for the records from Transmissions 22 and 48 may be compared to those estimated for Transmissions 6 and 7 (with binary failure simulated) in Figure 8. The spectrum from Transmission 22 is representative of the other four in the group with values of $m \leq 6.1\ \gamma$. The spectrum from Transmission 48, with $m = 7.2\ \gamma$, is representative of the other, Transmission 32, with $m = 7.6$. The records for these two periods exhibited values of $\sigma = 2.1$ and $1.9\ \gamma$, respectively. Transmission 23, with $m = 8.5\ \gamma$ and $\sigma = 0.5\ \gamma$, provided 535 field readings in Channel 27* and 2 in Channel 29*. Thus, very little variation was detected.

For the records with $m \leq 6.1\ \gamma$, the estimates of the spectra should be sufficiently accurate to permit a significant comparison between these records and those from Transmissions 6 and 7, since the discussion just presented concerning the detectable values of σ is again applicable. Thus, again the darth of power in the spectra is the range about 0.06 cps which is exhibited by these spectra in a comparison with those from Transmissions 6 and 7 indicates that fluctuations of the type observed during Transmissions 6 and 7 did not recur during these five transmission periods from which $m \leq 6.1\ \gamma$.

For the three records with $m = 7.2$, 7.6, and $8.5\ \gamma$, it is doubtful that the estimates of the power spectra are significant. The mean field values recorded in these cases indicate that most of the field readings fell within Channel 27* or above. With the binary inoperative, Channel 27* corresponds to a $7.0\ \gamma$ range of field values. Thus, field variations with $\sigma \leq 2.5\ \gamma$ could escape detection. Recall that Transmissions 6 and 7 (binary failure simulated) exhibited values of $\sigma = 2.8$ and 2.7, respectively.

Thus, despite the fact that, in all these cases, m could have been as small as $5.1\ \gamma$ or less with $\sigma < 0.07\ \gamma$, etc., it is not possible to conclude that fluctuations of the type under considerations were definitely absent. They well may have been, however, since in any of these three cases, the greatest number of readings outside of Channels 25* and 27* was less than 0.5 % of the total, while for Transmissions 6 and 7, these ratios were 5.3 and 2.2 %, respectively. In each of the three cases there were over 500 readings recorded. Transmissions 6 and 7 provided about 600 readings each.

Evidently then, field flucutations of the type recorded during Transmissions 6 and 7 did not recur during nine of the twelve transmission periods in this group, (64 bps, binary inoperative). However, during the other three periods fluctuations only slightly smaller on the average could have been present, but might not have been detected.

In comparing the data transmitted at 8 bps with those obtained by the simulation of 8 bps rate in the records from Transmissions 6 and 7, the first step is again the comparison of the values of m and σ calculated from the data. The values for records of 8 bps data obtained during normal operation of the intermittant binary element are listed in Table 6, along with the results from the simulated 8 bps data of Transmissions 6 and 7. A total of fifty transmissions at the normal 8 bps rate were received. Of the fifty, thirty-two yielded mean field values, $m \leq 7.4\ \gamma$, and rms deviations from the means, $\sigma \leq 1.1\ \gamma$. It is assumed that field variations of the type of interest were not recorded in any of these thirty-two records.

The criteria for this elimination were again selected for the reasons discussed during the consideration of the data obtained at 64 bps with the binary inoperative. The criterion $\sigma \leq 1.1\ \gamma$ was selected for ~~the~~ elimination of these records since it is slightly less than half the average value of $2.3\ \gamma$ which was obtained from the sixteen sets of simulated 8 bps data corresponding to Transmissions 6 and 7. Note, in Table 3, that the values of the rms deviations, σ, for these sixteen sets ranged from 1.4 to $3.0\ \gamma$. The criterion $m \leq 7.4\ \gamma$, in this case insures that half the readings fell within Channel 26 or lower channels, since Channel 26 and the channels just below provided relatively high-resolution which in turn insured accurate estimates of the deviations from mean values $\leq 7.4\ \gamma$. In this case, the maximum variations that could escape detection would correspond to $\sigma \leq 0.7\ \gamma$. The record of Transmission 128, an example of a record which exhibited an rms deviation of $1\ \gamma$, near the upper limit of $1.1\ \gamma$ which permitted elimination under this criterion, is shown in Figure 9. It may be compared with four of the sixteen sets of simulated 8 bps data, from the records of Transmissions

6 and 7, which are also plotted in Figure 9. Note that no readings of field values greater than those corresponding to Channel 26 were recorded during Transmission 128, whereas during Transmissions 6 and 7, such readings occurred about eight percent of the time.

There remain then eighteen sets of data from the normal 8 bps transmissions to be considered in more detail. In these cases, however, an investigation of the power spectra was not employed since the ratio of the sampling rate, in the 8 bps mode, to the high frequency cutoff of the magnetometer passband is too small to sufficiently reduce the possible effects of aliasing.

Of these remaining eighteen records of transmissions at the normal 8 bps data rate, thirteen exhibited values of $m \leq 7.4\ \gamma$ but values of $\sigma > 1.1\ \gamma$. Ten of these were eliminated following a further examination, the results of which indicated that the higher value of the rms deviation in each case was produced by a few isolated large field values which may have been due to the presence of noise in the telemetry system, but which, in any case, produced records which did not resemble those from Transmissions 6 and 7. The record of Transmission 91, an example of the records in this group of ten, is shown in Figure 10. Note that during 45 % of the time when measurements were recovered, the amplitudes of fluctuations in the field would have less than 2 γ, peak-to-peak, or 0.7 γ, rms, even though the calculated rms deviation was 1.6 γ. Also only 3 readings in 112 provided values in channels above Channel 26. This ratio during Transmissions 6 and 7 was about 8 % as just remarked.

All of the remaining eight records of normal 8 bps data exhibited mean field values > 4.9 γ, the value recorded for Transmission 7, and σ > 1.1 γ. In fact, all provided values of m $\geq$ 5.9 γ. The correlation between the higher field values in interplanetary space and higher levels of solar-interplanetary activity which was discussed earlier in this section, suggests that these records need not be of concern for our purposes. All of these eight transmission periods occurred during periods of enhanced solar-interplanetary activity.

However, it is possible to eliminate, as well, two of these eight records from further consideration. These two records, from Transmissions 144 and 161, exhibited values for m of 5.8 and 6.4 γ, respectively. They are shown in Figure 10. In both these cases, consecutive readings in Channel 25 or Channel 26 accounted for about 50 % of the points on the records. The range of field values contained within Channel 26 is 1.4 γ and that contained within Channel 25 is 2.2 γ. Variations within the larger of these ranges could produce a maximum rms deviation less than 0.80 γ. Since the fluctuations detected during Transmissions 6 and 7 were in this range only about 30 % of the time, it would appear that similar fluctuations could not be contained in these two records. Also, only four of the 312 readings indicated field values in channels above Channel 26, whereas for Transmissions 6 and 7 such readings occurred in about 8 % of the total.

In the remaining six of the eight records which exhibit mean field values > 5.9 γ, most of the field readings lie within Channels 27, 29 or above. The range of field values corresponding to Channel 27, for example, is 5.5 γ, so that fluctuations with $\sigma \leq 1.9$ γ would not produce changes in the recorded field values. Thus, during these six transmission periods, all of which occurred during periods marked by solar activity, geomagnetic storms, and Forbush decreases, the presence, in the vicinity of Pioneer 5, of field fluctuations with rms amplitudes in the range of interest would have gone undetected by the instrumentation.

Included in this group of six is the record of Transmission 116, with $m = 7.3$ γ and $\sigma = 3.3$ γ, shown in Figure 9. This record exhibits field variations which were unique when considered in terms of the rest of the measurements obtained during the flight on Pioneer 5. This event has been discussed in some detail in an earlier paper. (Sonett, Davis, and Coleman, 1962).

The results from the fifty records of normal 8 bps data may be summarized as follows: In none of these periods, during which the conditions in interplanetary space might be considered similar to those existing during Transmission 6 and 7, were field fluctuations of the type recorded during these two periods again detected farther from the earth. The similarity of conditions to which reference is made here is that determined by the conventional indices of solar-interplanetary activity and by the values of the mean interplanetary field recorded during a particular transmission period. Further, of those records obtained during periods of greater activity, none showed definite evidence of a recurrence of such field variations. However, there were six of these records in which such fluctuations could not have been identified with any degree of certainty had they occurred.

Next, in considering the data from the sixteen transmissions obtained at 8 bps when the binary element was inoperative, the first step as before is a comparison (See Table 7) between the results obtained from these data transmissions and the results produced from the records of Transmissions 6 and 7 by simulations of both the 8 bps data rate and the effect of the inoperative binary circuit. Eight of the sixteen sets of data probably did not exhibit effects of field fluctuations such as those of interest here since they exhibited values of $m \leq 6.1\ \gamma$ and $\sigma \leq 1.1\ \gamma$. This value for m was chosen as in the case of the 64 bps data involving the inoperative binary. The value for $\sigma \leq 1.1\ \gamma$ is half the smallest value exhibited by the sixteen sets simulated from Transmissions 6 and 7 as was shown in Table 2. Thus, these eight sets of data show no indication of a recurrence of the fluctuations under consideration. Again, as in the case of the normal 8 bps data, the comparison of power spectra was ruled out as a further test for the presence of the fluctuations.

Accordingly, other criteria were employed in a further analysis of the remaining eight records from the transmissions during which the binary was inoperative. All of the records in this group exhibited values of $m \geq 5.2\ \gamma$. In fact, with one exception, the values of m lay between 5.2 and 8.7 γ, inclusive. This exception, Transmission 31, yielded a mean field value of 15 γ. Thus, as mentioned previously, field variations of the type being considered might not have been detected had they in fact occurred during the transmission period. This particular record, shown in Figure 11, was obtained during the period of enhanced solar-interplanetary activity observed in mid-March, 1960.

The seven other records in this group of eight contained mostly readings of Channels 25* and 27*. With the binary inoperative the field ranges corresponding to these two channel numbers were 2.6 and 7.0 γ, respectively. The maximum rms fluctuation amplitudes that could be contained within these ranges are 0.9 and 2.5 γ, respectively, or 3.4 γ for their combined range. Thus, field fluctuations with values of σ in the range of interest could have occurred during these transmission periods.

In attempting to estimate the possibility of such an occurrence during each period, the relative field activity as determined by the rate of occurrence of changes between Channels 25* and 27* was considered. Such changes occurred within about 40 % of the intervals between samples during Transmissions 6 and 7. With the exceptions of Transmissions 26 and 35, such changes occurred within fewer than 12 % of the intervals during these transmission periods. The records from Transmissions 26 and 35, which exhibited such changes within 28 and 30 % of the recorded intervals, respectively, may be compared in Figure 11 with data from Transmissions 6 and 7.

The two records from Transmissions 26 and 35, of the sicteen records obtained at 8 bps when the binary was inoperative, resemble most closely the records obtained from Transmissions 6 and 7 by simulations of the effects of the inoperative binary and the sampling rate corresponding to 8 bps data transmission. Even in these two cases, the smaller number of field readings in ranges other than those corresponding to Channels 25* and 27* suggests that fluctuations of the type being sought were not responsible for the recorded field changes. The simulated record of Transmission 6 exhibited values without this range in 5 % of the readings, while those for Transmission 7 exhibited such values in 2 % of the readings. During Transmission 26, none were recorded and during Transmission 35 only one such value was recorded in 135 readings. This fact suggests that the field was actually fairly quiet but at a magnitude near 5.0 γ, the value at which the readout would change from Channel 25* to 27*. As a result, there is some indication that field variations such as those seen during Transmissions 6 and 7 did not recur during these seven transmission periods, although, as mentioned earlier, the possibility of such a recurrence cannot be eliminated because of the effective decrease in the sensivity of the detection equipment which resulted from the failure of the binary circuit.

Thus, the result of the comparison of the records from Transmissions 6 and 7 to those from the sixteen periods of data transmission at the 8 bps rate when the binary was inoperative, indicate that the field fluctuations under discussion did not recur during eight of these sixteen periods, probably did not recur during five others, and possibly did not recur during two of the remaining three. The other record of this group exhibited a mean value of 15 γ at which level the reduced magnetometer sensitivity from the AGC and from the effect of the inoperative binary renders the detection of such small field variations unlikely.

In this section, the results of an examination of magnetic field records from the eighty-three transmissions of data at the 64 and 8 bps data rates which succeeded Transmission 7 have been described. These records were examined, in various ways, in an effort to determine whether fluctuations in the measured component of the magnetic field, of the type which recorded during Transmissions 6 and 7, at geocentric distances of approximately 22 and 25 Re, respectively, were recorded during any of these later transmission periods when the spacecraft was beyond 30 Re. The examination indicates that such field fluctuations did not recur during any of the sixty-seven transmission periods in which their unambiguous detection would have been likely, except perhaps during Transmissions 35 and 116. These sixty-seven transmission periods were those during which the mean measured field recorded was $\leq 7.4\ \gamma$ or $\leq 6.1\ \gamma$ depending, respectively, upon whether or not the troublesome binary circuit was operating properly. The record from Transmission 116 evidently corresponds to an unusual event which, in any case, occurred during a period of unusually great solar-interplanetary activity that began late in March 1960. This fact and the mean field value of $7.3\ \gamma$ recorded during the transmission suggest that conditions during the period were not at all similar to those during Transmissions 6 and 7. Transmission 35 remains as a possible, although not very probable, case of a recurrence of field fluctuations such as those detected during Transmissions 6 and 7.

Discussion

In the last section, measurements of the magnetic fields beyond 26 Re obtained with instruments on board Pioneer 5 were compared to those obtained at 22 and 25 Re during the flihgt. On the basis of the results of this comparison it appears possible that the effects of the magnetosphere extended to a geocentric distance between 25.5 and 29.6 Re on the trajectory of Pioneer 5. In this section, then, such a possibility will be discussed in terms of two models postulated to account for the interaction of interplanetary medium and the magnetosphere.

The aforementioned shock-wave model of Spreiter and Jones (1963) is the first which will be employed to this purpose. In developing this model, Spreiter and Jones applied the results of Auer, Hurwitz, and Kilb (1961, 1962) in calculating the effects upon the interaction between the interplanetary plasma and the magnetosphere which would be produced by an interplanetary magnetic field transverse to the solar wind velocity and parallel or anti-parallel to the earth's dipolar magnetic moment. As mentioned previously, the shape of the magnetospheric boundary which was used is that calculated by Beard (1960). Traces of the magnetospheric boundary and the shock front shown in Figure 7 are provided by the model of Spreiter and Jones for values of the pertinent parameters as follows: solar wind relative speed, 600 km sec^{-1}; proton population density, 2.5 cm^{-3}, and interplanetary magnetic field, oriented as just described, of intensity 5 γ. These values for the density and velocity were selected as being representative of average conditions in interplanetary space during 'quiet' periods recorded by instruments aboard Mariner II. (Neugebauer and Snyder, 1962).

In obtaining the traces of the magnetospheric boundary and the shock front in the plane of the trajectory of Pioneer 5, which are shown in Figure 7, it was assumed that the corresponding surfaces were rotationally symmetrical about an axis through the center of the earth and parallel to the velocity of the solar wind relative to the earth. It was also assumed that this velocity vector was perpendicular to the dipole moment of the geomagnetic field. Since Pioneer 5 was within 15° of the geomagnetic equator, as shown in Figure 2, and since the angle between the solar wind velocity and the dipole moment varies by only about 11.5°, the assumption of this symmetry should result in a sufficiently accurate description of the model in the plane of the trajectory of Pioneer 5.

In this model, the distance from earth's center, r_o, of the boundary of the magnetosphere, measured in the direction opposite to that of the relative velocity of the solar wind was calculated by equating the static pressure within the magnetosphere to the dynamic pressure of the impinging solar wind. Thus

$$r_o = (8B_s^2/16 \pi m_p nv^2)^{1/6}$$

where r_o is measured in earth's radii, B_s is the field intensity at the geomagnetic equator, m_p is the proton mass, n is the proton population density in the solar wind, and v is the speed of the solar wind relative to earth. Here it is assumed that the intensity of the field at the nose of the magnetosphere is twice the intensity of the unperturbed geomagnetic equator at this distance, in accordance with the usual Chapman-Ferraro assumption that the boundary field is doubled as a result of currents in the region.

The static pressure $H^2/8 \pi$ of the interplanetary field has been neglected. Note also that a factor of $2^{1/6}$ is contained in the expression for r_o as a result of the shielding effect calculated for the shock wave. The solar wind parameters employed in the calculations which provided the magnetospheric boundary shown in Figure 7 yielded r_o = 10.15 Re.

In the following part of this discussion, occasionally it will be useful to employ the recent results of Snyder, Neugebauer, and Rao (1963) in estimating the solar wind velocities during the period of interest. These results, obtained from Mariner 2 data indicate that the K_p index of geomagnetic activity is a reliable index of the solar wind velocity in the region just beyond the magnetosphere and, further, that the relationship between the two quantities is linear. Based upon this relationship, the value of $K_p = 5-$ which was recorded for the reporting period within which Transmissions 3 and 4 occurred would correspond to a solar wind velocity $v \approx 650$ km sec^{-1}. The value $K_p = 2+$ reported for the period containing Transmission 8 would correspond to $v \approx 500$ km sec^{-1}.

From the data recorded during Transmissions 3 and 4, it was concluded that Pioneer 5 crossed the boundary of the geomagnetic cavity during the period between Transmissions 3 and 4, or between geocentric distances of 8.56 and 10.40 Re. This range along the trajectory of Pioneer 5 would correspond to a range for r_o between 7.2 and 9.2 Re.

Since the geomagnetic storm from which the magnetospheric system was recovering had been a gradual commencement type of moderate intensity, it is more likely that r_o for the boundary was closer to the latter distance. For $v = 650$ km sec^{-1}, the value $r_o \leq 9.2$ Re would require $n \geq 4.5$ cm^{-3}. Thus, on the basis of the data from Transmission 4 and this assumption concerning the relationship between the solar wind and velocity and the K_p index, the situation at the boundary of the geomagnetic cavity would appear to correspond to the effects expected for a moderate solar interplanetary disturbance.

Next, this same assumption will be employed in considering a shock front location which would be consistent with the Pioneer 5 data. Note, in Figure 7, that Transmission 7 was terminated when Pioneer 5 was just beyond 25.5 Re. Note also that the geocentric distance of the shock front measured along the radius vector to the position of Pioneer 5 would have been about 18.5 Re, according to the calculations for the model shown in the figure. If, however, the variations in the measured field which were detected at 25.5 Re were produced by the interaction of the solar wind and the magnetosphere, as is suggested by the results discussed in the previous section, the usual shock wave picture would require that the shock front be beyond 25.5 Re on the trajectory of Pioneer 5, since this picture would include an interplanetary medium unaffected by the presence of the magnetosphere upstream from the shock front.

The 'standoff' distance, d, of the shock front is the distance between the magnetospheric boundary and the shock front, measured along the line through the earth's center and parallel to the velocity of the solar wind relative to the earth. For the model under discussion, the parameter of importance in determining the standoff distance is the Alfven mach number, M_A, of the interplanetary plasma, where $M_A = v/v_A$, $v_A = (B^2/4\pi n m_p)^{1/2}$ is the Alfven velocity for the interplanetary medium, and the other quantities are as previously defined.

The parameters employed by Spreiter and Jones in calculating the positions of the magnetospheric boundary and the shock front shown in Figure 7, yielded $M_A = 8.71$ and a standoff distance of 3.8 Re or about 0.38 R_o. As was just mentioned, the geocentric distance to the shock front, measured along geocentric radius to Pioneer 5 at the time of Transmission 7, would have been about 8.6 Re in the situation corresponding to the model shown in the figure.

If, however, it be assumed that Pioneer 5 was still within the interaction region at 25.5 Re, the possibility that a shock front was beyond this range must be considered. In this case, the spacecraft would have traversed the front during the period between Transmissions 7 and 8 or between 25.6 and 29.7 Re. For a 5 γ component of the interplanetary field transverse to the solar wind velocity, a rough extrapolation of the results of Spreiter and Jones provides a corresponding range for M_A from 4 to somewhat greater than 2. If it be assumed, for the values of K_p at the times of Transmissions 7 and 8, that $v \approx 500$ km sec^{-1}, this range of values for M_A with $B = 5\ \gamma$ would require a range for n from 0.7 to 0.2 protons per cm^3. This range is close to the lower limit for n which has been recorded by the Mariner 2 plasma probe in the cases studied so far (Neugebauer, private communication), but such values of n are evidently realized on occasion. An estimate of the upper limits for the range of n which would provide the desired value of r_o +d can be obtained using v = 300 km sec^{-1} which, from the Mariner 2 results of Snyder, Neugebauer, and Rao (1963), appears to be a valid lower limit on the solar wind velocity. This estimate provides a range of n from 2.1 to 0.5 protons per cm^3. Evidently then the collisionless shock wave could provide an interaction region which extends to geocentric distances beyond that of Pioneer 5 at the termination of Transmission 7, but the values of n and v would be lower than those expected for active periods and the corresponding range for r_o would be 12-15 Re which is somewhat greater than even the 10-11 Re indicated for quiet periods by the data from Explorer 12. (Cahill and Amazeen, 1963).

Features of the observations which are not consistent with this picture of a low mac number shock wave are the changes in the characteristics of the measured fields which evidently occurred between Transmissions 5 and 6. Recall that, in the section pertaining to observations to 26 Re, these changes were discussed in terms of the possibility that the interaction region might consist of two sub-regions, which in this case would have been separated by a boundary located between 15.3 and 21.8 Re on the Pioneer 5 trajectory (Coleman, 1962).

However, these changes also may have been the results of changes in M_A and B that resulted in the recovery from the geomagnetic storm which occurred during this period. Thus, the shock front may have been considerably closer to the earth at the time of Transmission 5 than it was during Transmission 6 and may have been even more distant at the time of Transmission 7. Such a change could account for the lack of observable dependence upon r which was exhibited by m and σ in these last two records. Evidence for a significant change in the state of the magnetosphere during the period between 1530 and 2000 GMT appears in ground station magnetograms. At Fredricksburg and San Juan, for examples, in-phase decreases in excess of 50 γ were recorded in the horizontal component of the geomagnetic field during this period. Comparisons, by Nishida and Cahill (1964), between magnetic fields, measured with instruments aboard Explorer XII, and ground station measurements indicate that such a decrease might be expected while the boundary of the magnetosphere is moving outward.

In view of the relatively low values of v and n which are theoretically required to provide a shock front at such extreme geocentric distances, it is worthwhile to consider an alternative model for the transition region which has been described by Bernstein, Fredricks, and Scarf (1964). This model provides an abrupt transition from the fields of the geomagnetic cavity to the disordered fields of the transition region as does the shock wave model. However, in place of the shock front [illegible] to the state of the interplanetary medium, a gradual transition is indicated. In the justification for this model, it is argued that the medium within the relatively thin Chapman-Ferraro type of interaction region exhibits a "two-stream" instability. Thus, for example, a perturbation consisting of currents generated by the electric fields from charge separation may produce ion waves which are not damped in an electron-proton plasma with finite drift and unequal temperatures for the two constituents.

The fields associated with these waves, in turn, allow "fast" diffusion of plasma through the magnetic field so that the transition region is greatly extended, thereby providing a board, disordered transition region between the magnetosphere and the interplanetary medium. However, in terms of average quantities such as m, this transition region should exhibit a relatively smooth transition from the values just beyond the magnetosphere to a lower value in interplanetary space. The geocentric distance to the outer limit of the transition region, according to this model, does not have a finite value. Note that this model does not allow for the possibility of two sub-regions in the region of interaction.

The other feature of this model which is attractive when considered in terms of the data from Pioneer 5, is inner boundary for the transition region which agrees with observations obtained to date, e.g., during quiet times, 8-10 Re. Of course, other mechanisms for broadening a transition region of the Chapman-Ferraro type have been postulated, but most of them do not provide a broadening so extensive.

Summary

In the preceding sections, the magnetic field measurements obtained with instruments aboard Pioneer 5 in the distant geomagnetic cavity and in the transition region beyond were described. It was remarked that many of the observations have since been confirmed by more sophisticated experiments. However, in the course of the description, it was noted that fluctuating fields with possibly unique characteristics were observed at surprisingly great geocentric distances. In an attempt to determine whether these fluctuations were indeed unique to regions of interaction between 'bodies' composed of tenuous plasma and magnetic fields moving at high relative velocities, such as that surrounding the geomagnetic cavity, records from later transmission periods during which Pioneer 5 was certainly in interplanetary space were examined for recurrences of similar disturbances. On the basis of this examination, it was concluded that these relatively distant fluctuating fields might well be a phenomenon associated with the region of transition between the magnetospheric and the interplanetary media. Finally, two models for the transition region were discussed in an attempt to account for the relatively great radial extent required of the transition region if these fluctuations were indeed characteristic of this region.

The two models for the region were that of Spreiter and Jones (1963), which includes a collisionless shock wave as a result of the flow of the solar wind past the magnetosphere and that of Bernstein, Fredericks, and Scarf (1963) which includes a broad region through which occurs a continuous transition to the state of the interplanetary medium. It was concluded that the shock wave model could account for the distant fluctuations, but that the corresponding shock would be relatively weak, with M_A between 2 and 4. However, a weak shock in an interplanetary medium with magnetic fields near 5 γ would also result in a rather large value for r_o the geocentric radial distance to the boundary of geomagnetic cavity measured along the radius parallel to the velocity of the solar wind relative to the earth (roughly, along the earth-sun line). The observations may be accounted for also by the latter model which would allow the transition region to extend to relatively great distances from the earth and, at the same time provide values for r_o in a range close to that observed to date.

Several difficulties attended the analysis of these observations. These difficulties result, in the first place, from the fact that the fields were not measured continuously. Further, since the spacecraft was on an interplanetary trajectory, only one traversal by the interaction region was possible. Finally, the magnetosphere and the interplanetary medium were evidently changing states during the period of these observations. The resulting uncertainties allowed the speculation that changes in the state of the nearby interplanetary medium produced the effects which, had the conditions in nearby space been more stable, would have been consistent with the existence of two sub-regions in the interaction region. This speculation, in turn, allowed the possibility that either of the two models described above could account for the observations. However, it is felt that an actual subdivision of the interaction region remains a distinct possibility, under the assumption that the field variations recorded during Transmissions 6 and 7 were part of the interaction region. Of course the evidence for this assumption, presented in the foregoing, is not conclusive.

In considering this possibility that the interaction region might consist of two subregions, it becomes apparent immediately that such a subdivision would be inconsistent with the model of the broad transition region, since, in this case, most of the quantities of interest are expected to decrease monotonically with increasing geocentric range, through the transition region, to their interplanetary values. However, since the behavior expected of the interplanetary medium near such a shock front has not been established, the existence of two subregions behind the shock front, or perhaps of a relatively broad shock layer behind which is a single interaction region should be considered.

Along the trajectory of Pioneer 5, the outer sub-region would have been between 3.8 and 14.4 Re in radial extension. Here again, these values must be employed with caution, since, as just mentioned, conditions evidently were not constant in this region during this portion of the flight. However, one of the parameters of the interplanetary medium which might be expected to bear upon the radial extent of such an outer sub-region is the radius of gyration of the protons in the medium. For the case in which $v = 500$ km sec^{-1} and $B = 5\ \gamma$, this radius is about 10^3 km so that the outer subregion would have been some 20 to 90 gyro radii in radial extent along the Pioneer 5 trajectory and probably somewhat less along the radius through the center of the earth and parallel to the velocity of the solar wind relative to the earth.

On the other hand, one should bear in mind the possibility that M_A had decreased to about 2, or perhaps less, during the latter portion of the period of interest, thereby changing qualitatively the characteristics of the interaction region. A more detailed analysis presently underway, of the spectra of the field variations recorded during Transmissions 4, 5, 6, and 7 may provide information bearing upon these speculations.

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TABLE 1

PIONEER V

Distribution of Periods of Data Transmissions According to Information Rates

INTERVAL - 1960		Information		Rates
From	To	64	8	1
11 Mar (1300 GMT)	12 Mar (0600 GMT)	9	0	0
12 Mar (0600 GMT)	18 Mar	12	16	0
18 Mar	20 Mar	4	0	6
20 Mar	15 Apr	0	50	82
16 Apr	17 May	0	0	115
Totals		25	66	203
Grand Total				294

TABLE 2

SUMMARY OF DATA OBTAINED AT 8 AND 64 BPS.

Transmission Number	Date (1960)	Time On (GMT)	Duration (min)	Data Rate (bits/sec)	Binary Failure	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
2	11 March	14:30	14	64		141.8	18.0
3	11	15:31	13	64		70.4	6.4
4	11	16:31	15	64		41.0	20.7
5	11	18:31	13	64		26.8	11.0
6	11	22:00	15	64		4.5	2.2
7	11	23:46	14	64		4.9	2.1
8	12	02:16	14	64		4.8	1.0
9	12	05:01	20	64		3.6	0.7
10	12	07:19	11	8		4.2	1.3
11	12	11:33	12	8	√	3.9	1.1
12	12	15:31	28	64	√	5.0	2.1
13	12	18:31	13	64		3.6	0.6
14	12	22:31	14	8	√	3.6	0.8
15	13	01:31	15	64	√	3.4	0.9
16	13	07:28	2	8	√	3.7	0.0
17	13	14:01	27	64	√	2.8	0.7
18	13	18:32	12	64	√	2.7	0.6
19	13	22:42	8	8	√	3.7	0.0
20	14	01:06	14	8	√	6.2	2.4
21	14	07:02	18	8	√	2.3	0.0
22	14	14:01	29	64	√	5.4	2.3

TABLE 2 (Continued)

Transmission Number	Date (1960)	Time On (GMT)	Duration (min)	Data Rate (bits/sec)	Binary Failure	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
23	14	18:43	14	64	✓	8.5	0.5
24	14	22:31	13	8	✓	8.3	1.1
25	15	03:01	29	8	✓	8.3	1.0
26	15	07:01	28	8	✓	7.1	2.2
27	15	14:03	27	64	✓	4.1	1.3
29	15	22:27	17	8	✓	7.9	1.6
30	16	02:01	30	8	✓	8.7	1.4
31	16	07:01	34	8	✓	14.8	4.1
32	16	14:0[illegible]	26	64	✓	7.6	1.4
34	16	22:01	20	8	✓	3.7	1.4
35	17	02:01	29	8	✓	5.2	2.2
36	17	07:01	34	8	✓	3.4	0.8
37	17	14:02	28	64	✓	5.4	2.4
38	17	18:01	15	64	✓	5.9	2.5
39	17	22:31	14	8	✓	3.7	0.0
42	18	14:26	29	64		3.8	0.4
43	18	18:01	14	64		3.7	0.4
47	19	14:01	30	64	✓	5.0	2.2
48	19	18:01	15	64	✓	7.2	2.1
52	20	14:32	28	8		5.5	0.6
53	20	18:01	15	8		4.2	0.8
57	21	14:40	17	8		5.2	0.8
58	21	15:01	11	8		4.6	1.0
59	21	18:01	14	8		2.6	0.9

TABLE 2 (Continued)

Transmission Number	Date (1960)	Time On (GMT)	Duration (min)	Data Rate (bits/sec)	Binary Failure	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
67	23	18:24	30	8		2.5	0.6
71	24	14:01	29	8		7.7	1.8
72	24	17:02	14	8		8.0	1.7
76	25	13:01	29	8		5.6	0.4
77	25	17:01	14	8		3.9	0.7
81	26	13:11	34	8		3.9	0.6
82	26	17:02	14	8		3.4	2.0
86	27	13:03	34	8		4.5	0.9
87	27	17:01	14	8		2.9	0.6
91	28	13:01	34	8		4.6	1.6
92	28	17:01	14	8		5.5	0.6
97	29	13:27	35	8		3.8	3.0
98	29	17:01	14	8		3.8	0.5
104	30	13:01	34	8		5.3	1.3
105	30	17:02	18	8		5.0	1.4
110	31	13:01	39	8		18.4	0.8
111	31	17:01	14	8		18.0	1.5
116	1 April	12:46	29	8		7.3	3.3
117	1	16:46	19	8		16.3	3.5
122	2	12:41	35	8		2.7	0.5
123	2	16:43	19	8		2.9	1.5
128	3	12:26	14	8		3.5	1.0
129	3	16:31	19	8		3.1	0.6

TABLE 2 (Continued)

Transmission Number	Date (1960)	Time On (GMT)	Duration (min)	Data Rate (bits/sec)	Binary Failure	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
134	4	12:30	45	8		3.4	0.8
135	4	16:31	19	8		5.5	0.6
138	5	12:32	39	8		5.5	1.3
139	5	16:51	39	8		3.6	1.1
140	6	12:20	35	8		3.1	0.7
141	6	15:07	14	8		4.4	1.9
142	6	16:51	50	8		4.1	1.1
143	7	12:17	43	8		5.7	1.3
144	7	16:58	45	8		5.8	1.7
148	8	12:10	25	8		3.2	0.7
153	9	11:57	29	8		3.0	0.7
154	9	17:06	24	8		3.8	0.3
161	11	11:42	28	8		6.4	1.8
162	11	16:47	29	8		2.7	0.5
166	12	11:36	26	8		3.0	0.9
167	12	17:02	30	8		2.8	0.7
170	13	16:27	29	8		2.9	0.6
173	14	11:32	34	8		2.9	0.9
174	14	17:10	21	8		1.0	0.5
177	15	12:15	16	8		3.8	0.3
178	15	17:01	29	8		2.8	0.5

TABLE 3

PIONEER V

Parameters of Measured Magnetic Fields from Records of Transmissions 6 and 7 with Modes of Operation (other than normal 64 bps) Simulated.

Numbers marked with an asterisk indicate records in which the effect of the inoperative binary has been simulated.

Transmission Number	Data Rate (bits per sec)	Mean Value, m (gamma)	RMS Deviation, σ (gamma)
6	64	4.5	2.2
7	64	4.9	2.1
*6	64	5.5	2.8
*7	64	5.8	2.7
6-1	8 Simulated	4.6	3.0
6-2	"	4.2	1.9
6-3	"	4.8	2.1
6-4	"	4.6	1.7
6-5	"	4.5	1.8
6-6	"	4.6	2.4
6-7	"	4.7	3.0
6-8	"	4.3	1.4
6-Average	8 Simulated	4.5	2.2

TABLE 3 (Continued)

Transmission Number	Data Rate (bits per sec)	Mean Value, m (gamma)	RMS Deviation, σ (gamma)
7-1	8 Simulated	4.6	1.8
7-2	"	5.2	2.7
7-3	"	5.1	2.1
7-4	"	5.3	2.0
7-5	"	5.0	2.4
7-6	"	4.6	2.0
7-7	"	4.4	1.6
7-8	"	4.5	1.7
7-Average	8 Simulated	4.8	2.4
6-1*	8 Simulated	5.8	3.3
6-2*	"	5.0	2.5
6-3*	"	5.7	2.4
6-4*	"	5.7	2.4
6-5*	"	5.2	2.3
6-6*	"	5.5	2.7
6-7*	"	5.5	3.6
6-8*	"	5.5	2.4
6*-Average	8 Simulated	5.3	2.7

TABLE 3 (Continued)

Transmission Number	Data Rate (bits per sec)	Mean Value, m (gamma)	RMS Deviation, σ (gamma)
7-1*	8 Simulated	5.7	2.7
7-2*	"	6.4	3.3
7-3*	"	6.1	3.1
7-4*	"	6.4	2.4
7-5*	"	5.8	2.7
7-6*	"	5.4	2.7
7-7*	"	5.1	2.2
7-8*	"	5.4	2.3
7*-Average	8	5.8	2.7

TABLE 4

PIONEER V

Characteristics of Records Obtained at 64 BPS Rate

Transmission No.	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
6	4.5	2.2
7	4.9	2.1
8	4.8	1.0
9	3.6	0.7
13	3.6	0.6
42	3.8	0.4
43	3.7	0.4

TABLE 5

PIONEER V

Characteristics of Records Obtained at 64 BPS Rate, with the Binary Circuit Inoperative, Compared to Those of Records from Transmissions 6 and 7.

Transmission Number	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
6 (simulated binary failure)	5.5	2.8
7 (simulated binary failure)	5.8	2.7
12	5.0	2.1
15	3.4	0.9
17	2.8	0.7
18	2.7	0.6
22	5.4	2.3
23	8.5	0.5
27	41	1.3
32	7.6	1.9
37	5.4	2.4
38	5.9	2.5
47	5.0	2.2
48	7.2	2.1

TABLE 6

PIONEER V

Characteristics of Records Obtained at 8 BPS Rate Compared to Those of Records from Transmissions 6 and 7

Transmission No.	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
6(Simulated 8 bps)	4.5 average	2.2 average
7(Simulated 8 bps)	4.8 average	2.4 average
10	4.2	1.3
52	5.5	0.6
53	4.2	0.8
57	5.2	0.8
58	4.6	1.0
59	2.6	0.9
67	2.5	0.6
71	7.7	1.8
72	8.0	1.7
76	5.6	0.4
77	3.9	0.7
81	3.9	0.7

Transmission No.	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
82	3.4	2.0
86	4.5	0.9
87	2.9	0.6
91	4.6	1.6
92	5.5	0.6
97	3.8	3.0
98	3.8	0.5
104	5.3	1.3
105	5.0	1.4
110	18.4	0.8
111	18.0	1.5
116	7.3	3.3
117	16.3	3.5
122	2.7	0.5
123	2.9	1.5
128	3.5	1.0
129	3.1	0.6
134	3.4	0.8
135	5.5	0.6

TABLE 6 (Continued)

Transmission No.	Mean Field, m (gamma)	RMS Deviation, σ (gamma)	Transmission No.	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
138	5.5	1.3	161	6.4	1.8
139	3.6	1.1	162	2.7	0.5
140	3.1	0.7	166	3.0	0.9
141	4.4	1.9	167	2.8	0.7
142	4.1	1.1	170	2.9	0.6
143	5.7	1.3	173	2.9	0.9
144	5.8	1.7	174	1.0	0.5
148	3.2	0.7	177	3.8	0.3
153	3.0	0.7	178	2.8	0.5
154	3.8	0.3			

TABLE 7

PIONEER V

Characteristics of Records Obtained at 8 BPS Rate, with the Binary Circuit Inoperative, Compared to Those of Records from Transmissions 6 and 7.

Transmission Number	Mean Field, m (gamma)	RMS Deviation, σ (gamma)
6(simulated 8 bps, simulated binary failure)	5.3 average	2.7 average
7(simulated 8 bps, simulated binary failure)	5.8 average	2.7 average
11	3.9	1.1
14	3.6	0.8
16	3.7	0.0
19	3.7	0.0
20	6.2	2.4
21	2.3	0.0
24	8.3	1.1
25	8.3	1.0
26	7.1	2.2
29	7.9	1.6
30	8.7	1.4
31	14.8	4.1
34	3.7	1.4
35	5.2	2.2
36	3.4	0.8
39	3.7	0.0

FIGURE CAPTIONS

Figure 1: Projections of the near-earth trajectory of Pioneer 5. The coordinates are earth-centered. The XY-plane is the plane of the earth's equator. The positive X-direction is the earth-sun direction at vernal equinox. The positive Z-direction is north along the earth's spin axis. The spacecraft transmitted data from positions indicated by the heavy dashes along the projections.

Figure 2: Geomagnetic latitude versus distance from the center of the earth for the near-earth portion of the trajectory of Pioneer 5.

Figure 3: Measurements of the magnetic field recorded from Pioneer 5 during Transmissions 2-8. The data shown are one-minute averages (averages over 40 measurements) and are indicated by flags or dots as explained in the text. The solid curves represent the values expected at these geocentric distances for the measured field component from the geomagnetic dipole. The measured component is that transverse to the spin axis of the spacecraft.

Figure 4: Measurements of the magnetic field recorded from Pioneer 5 during Transmissions 3-8. The points shown represent sequences of individual measurements obtained during portions of the indicated transmission periods. The measurements were obtained at 1.5 sec. intervals. The solid curves, as in Figure 3, represent the values of the measured component expected from the geomagnetic dipole.

Figure 5: Mean values, m, of the measured magnetic field and mean square deviations from the means, σ^2, recorded during various periods of data transmission from Pioneer 5. Except for Transmission 2, the means were taken over the entire transmission periods. Values of σ^2 are shown for Transmissions 5-8 only. The solid lines, representing two values of exponential dependence upon geocentric distance, r, are shown for reference. Note the departures from these lines between Transmissions 5 and 6 in both m and σ^2.

Figure 6: Estimates of the power spectra of the field variations recorded by Pioneer 5 during Transmissions 4-9. In comparing the spectra of Transmissions 8 and 9 to those of Transmissions 6 and 7, note the differences in the lower-frequency half of the spectra particularly in the frequency ranges about 0.6 cps.

FIGURE CAPTIONS (Continued)

Figure 7: Approximate traces of the boundaries of the magnetosphere and shock front in the plane of the trajectory of Pioneer 5. The boundaries were calculated by Spreiter and Jones (1963) for a solar wind of 2.5 protons cm^{-3} and 600 km/sec with a magnetic field of 5 γ.

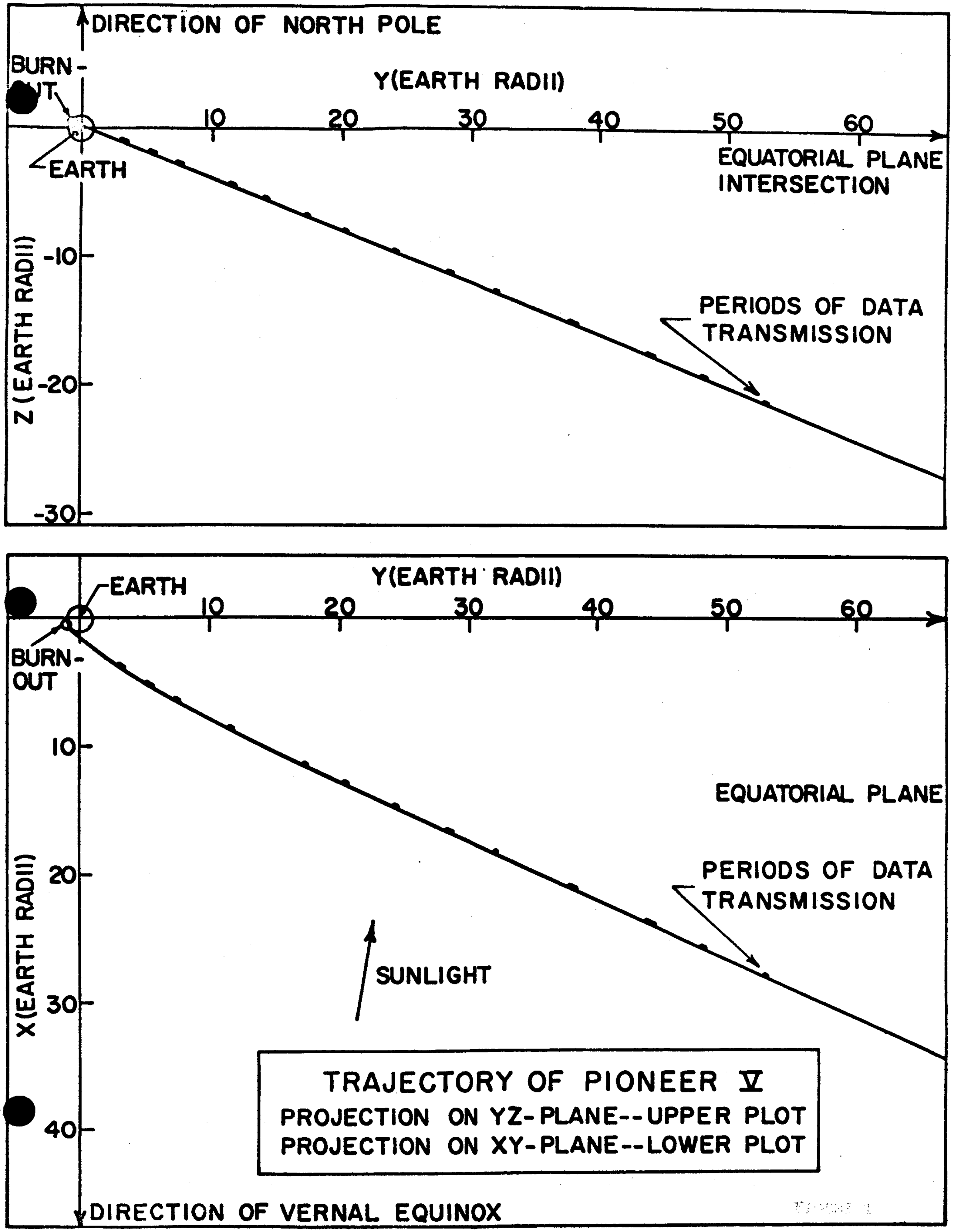
Figure 8: Estimates of the power spectra for records of field variations obtained while a binary circuit was inoperative. The spectra shown for Transmissions 22 and 48 are typical of those obtained from such records. The spectra shown for the records from Transmissions 6 and 7 were obtained after a simulation of the effects of this failure.

Figure 9: Examples of field measurements recorded at the 8 bps data rate during periods in which the measured field exhibited relatively high levels of activity as determined by values of σ obtained from the records. Additional examples are shown in Figure 10. The measurements plotted for Transmissions 6 and 7 include 2 of 8 sets of data formed by taking every 8th recorded measurement. This process simulates operation at 8 bps in records obtained at 64 bps.

FIGURE CAPTIONS (Continued)

Figure 10: Additional examples of field measurements recorded at 8 bps during periods in which the measured field exhibited relatively high levels of activity. (Other examples are shown in Figure 9). These measurements may be compared with samples of those obtained during Transmissions 6 and 7 which are shown in Figure 9.

Figure 11: Examples of field measurements recorded at 8 bps while binary circuit was inoperative and during periods in which the measured field exhibited relatively high levels of activity. The measurements shown from Transmissions 6 and 7 were obtained by a simulation, described in the text, of the effects of the 8 bps data rate and the inoperative binary circuit.



TRAJECTORY OF PIONEER V
PROJECTION ON YZ-PLANE--UPPER PLOT
PROJECTION ON XY-PLANE--LOWER PLOT

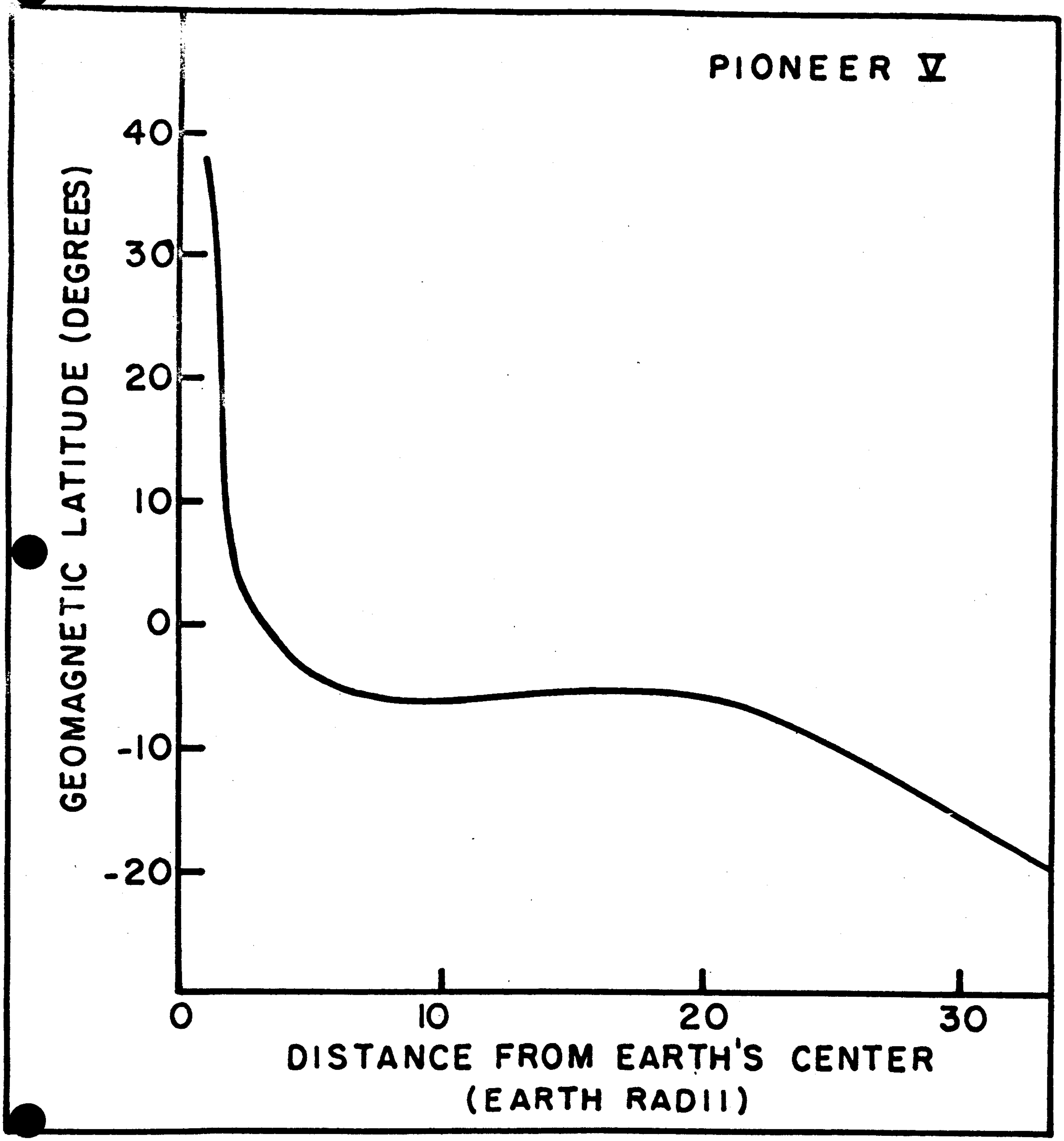

PIONEER V
GEOMAGNETIC LATITUDE (DEGREES)
40
30
20
10
0
-10
-20
0
10
20
30
DISTANCE FROM EARTH'S CENTER
(EARTH RADII)

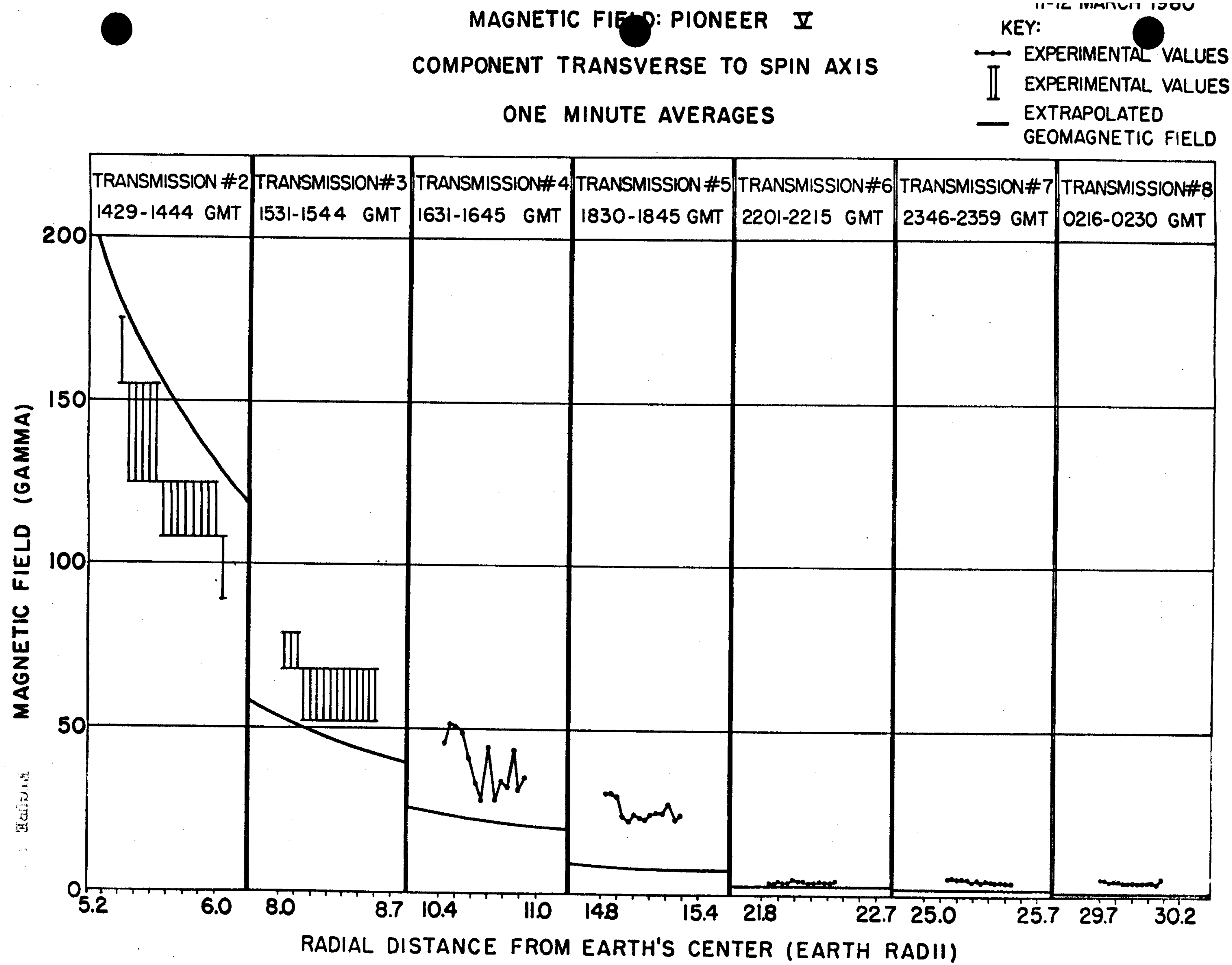
FIGURE 2

MAGNETIC FIELD: PIONEER V

COMPONENT TRANSVERSE TO SPIN AXIS

ONE MINUTE AVERAGES

11-12 MARCH 1960



FIGURE

MAGNETIC FIELD: PIONEER V

COMPONENT TRANSVERSE TO SPIN AXIS

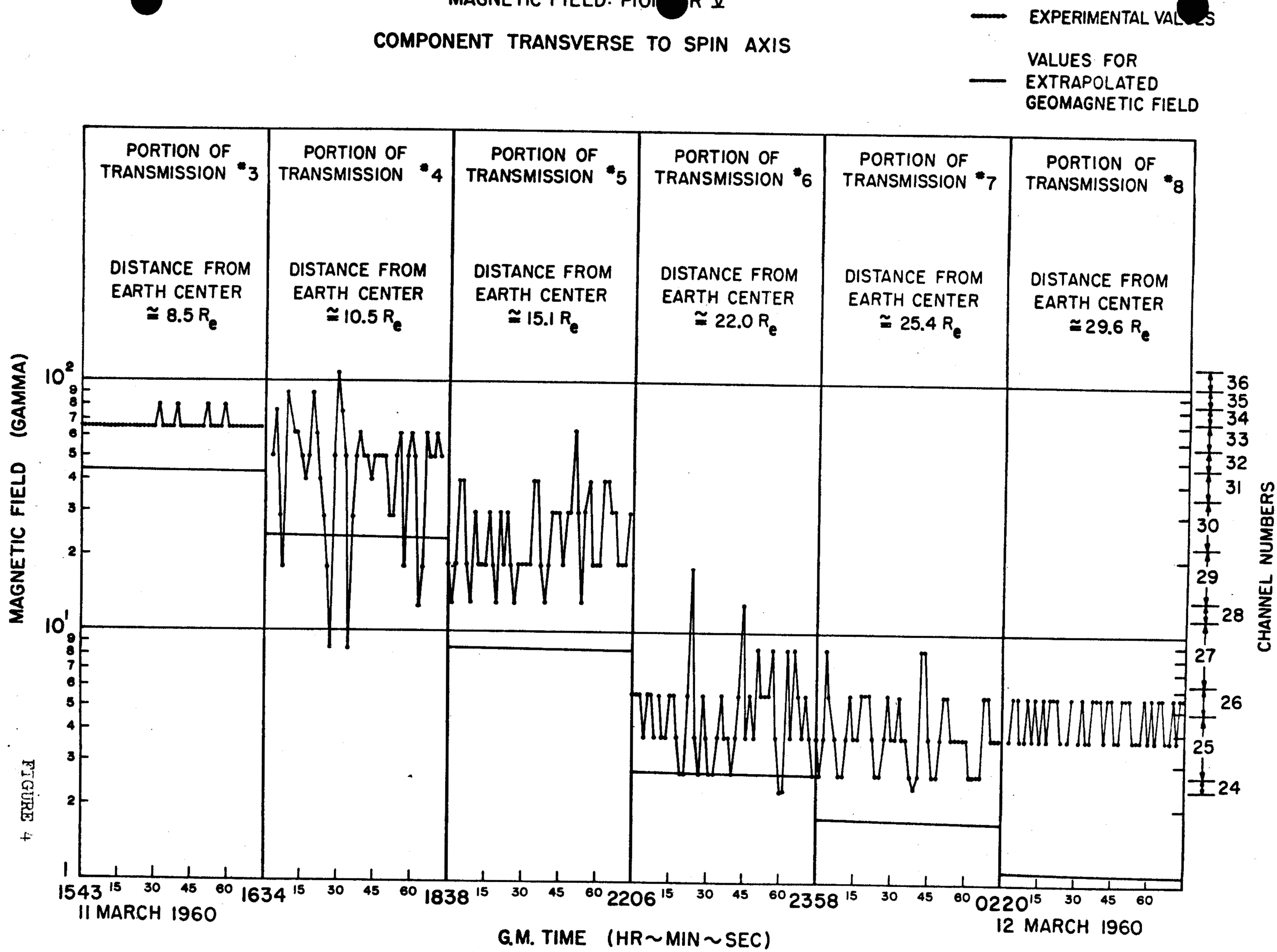
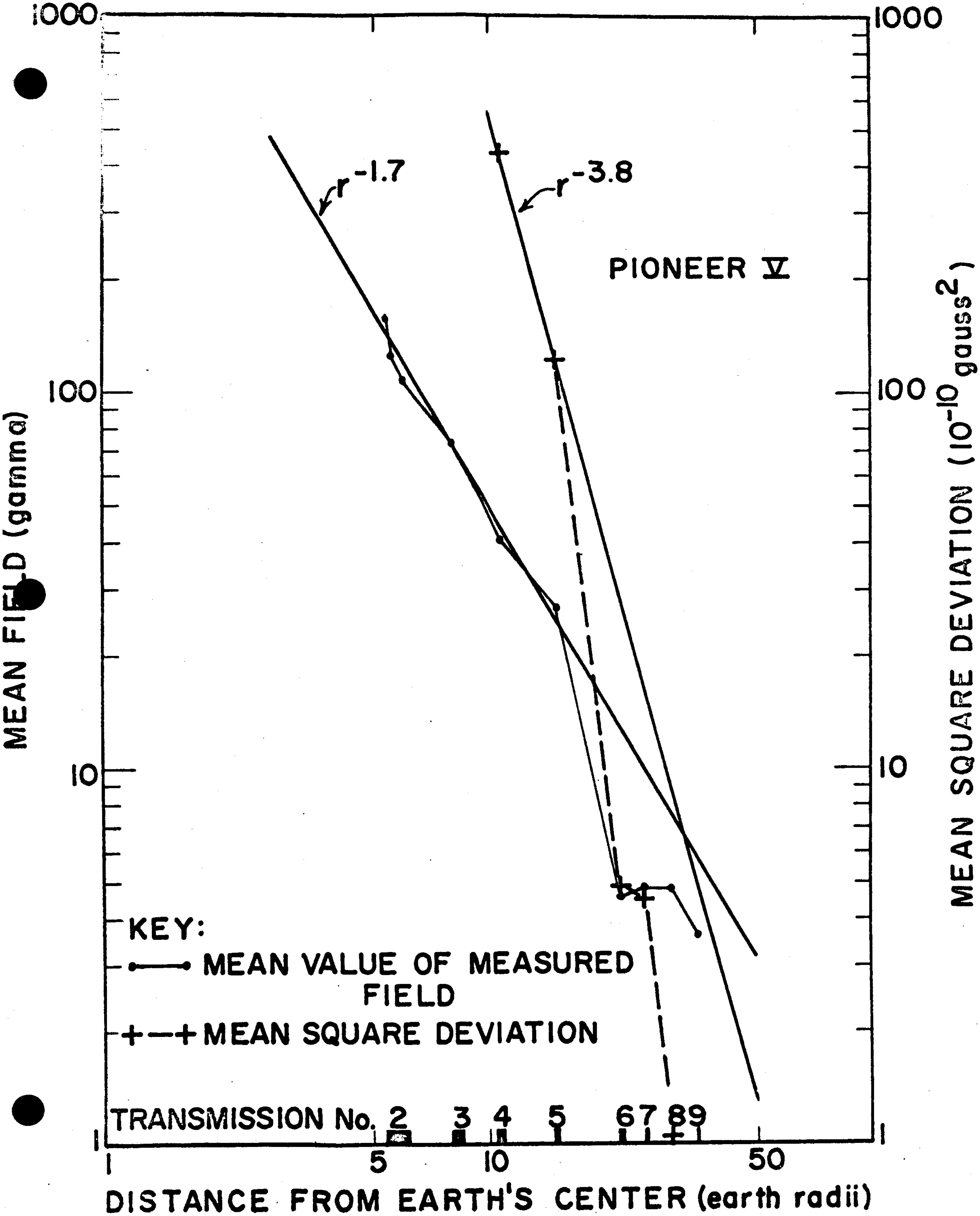
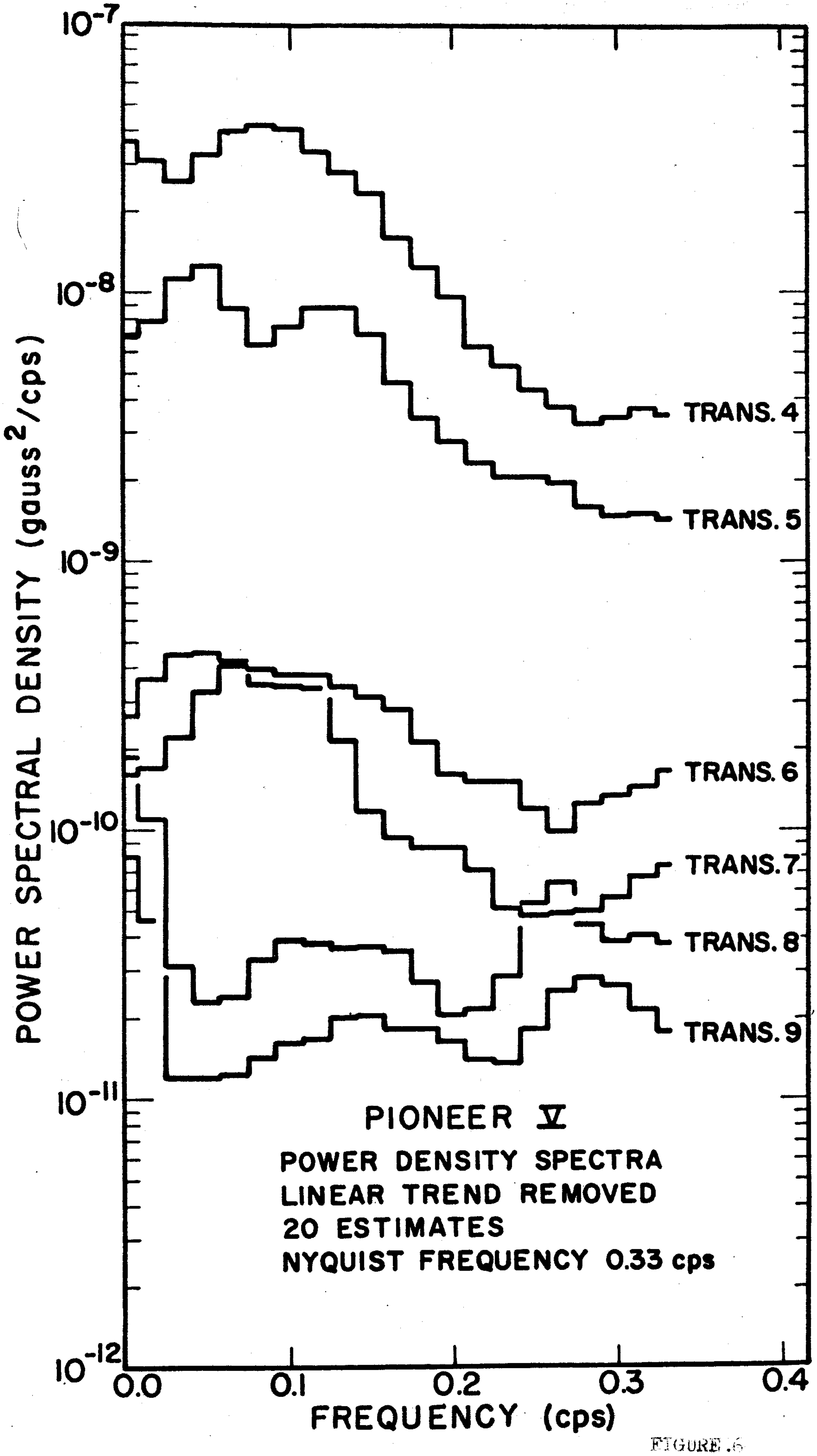


FIGURE 4



1000
100
10
1
MEAN FIELD (gamma)
1000
100
10
1
MEAN SQUARE DEVIATION (10^{-10} gauss^2)
$r^{-1.7}$
$r^{-3.8}$
PIONEER V
KEY:
MEAN VALUE OF MEASURED FIELD
MEAN SQUARE DEVIATION
TRANSMISSION No. 2 3 4 5 6 7 8 9
1
5
10
50
DISTANCE FROM EARTH'S CENTER (earth radii)

FIGURE 5



10-7
10-8
10-9
10-10
10-11
10-12
POWER SPECTRAL DENSITY (gauss2/cps)
TRANS. 4
TRANS. 5
TRANS. 6
TRANS. 7
TRANS. 8
TRANS. 9
PIONEER V
POWER DENSITY SPECTRA
LINEAR TREND REMOVED
20 ESTIMATES
NYQUIST FREQUENCY 0.33 cps
0.0
0.1
0.2
0.3
0.4
FREQUENCY (cps)

FIGURE 6

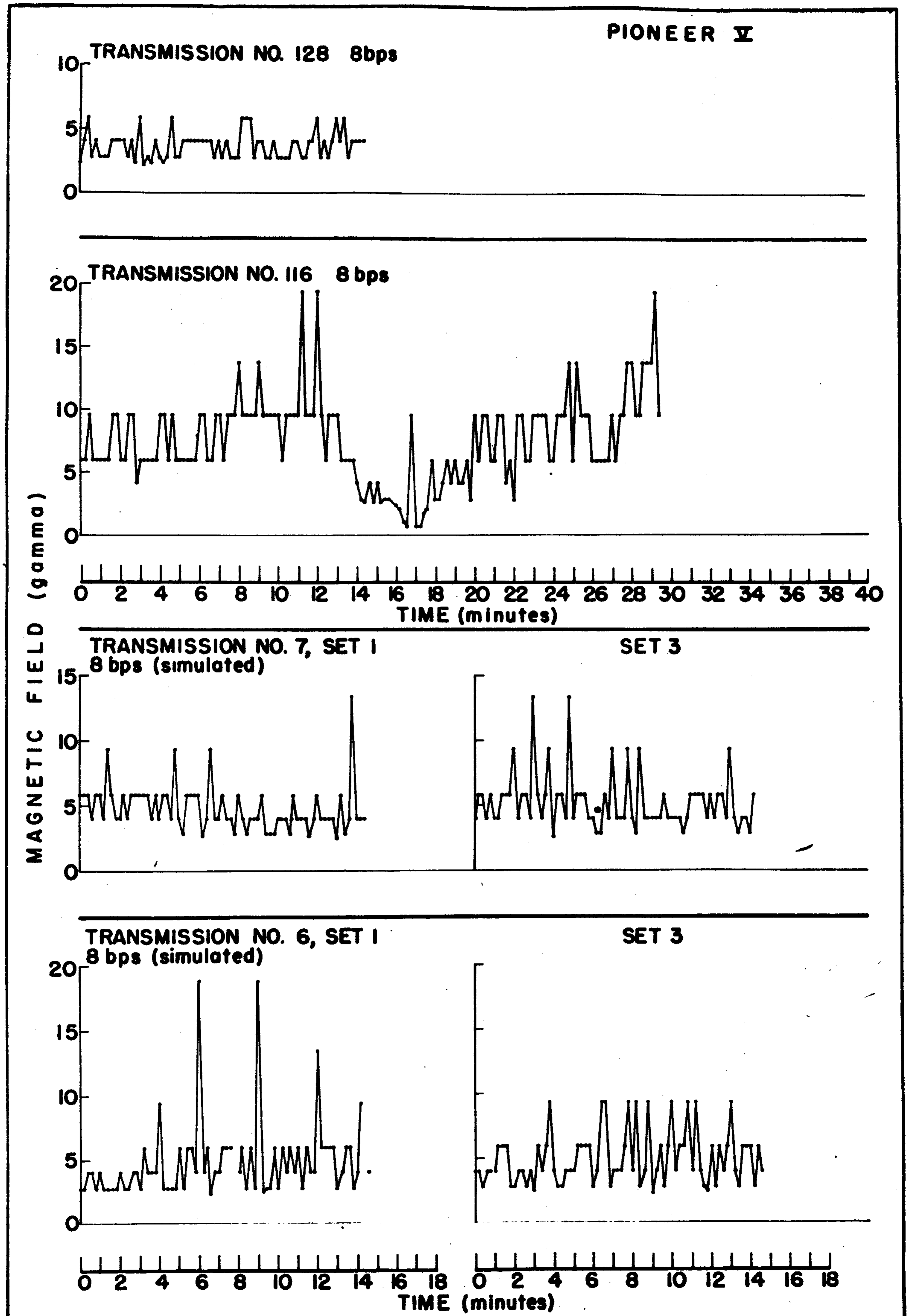

PIONEER V
TRANSMISSION NO. 128 8bps
TRANSMISSION NO. 116 8 bps
MAGNETIC FIELD (gamma)
TIME (minutes)
TRANSMISSION NO. 7, SET 1
8 bps (simulated)
SET 3
TRANSMISSION NO. 6, SET 1
8 bps (simulated)
SET 3
TIME (minutes)

FIGURE 9

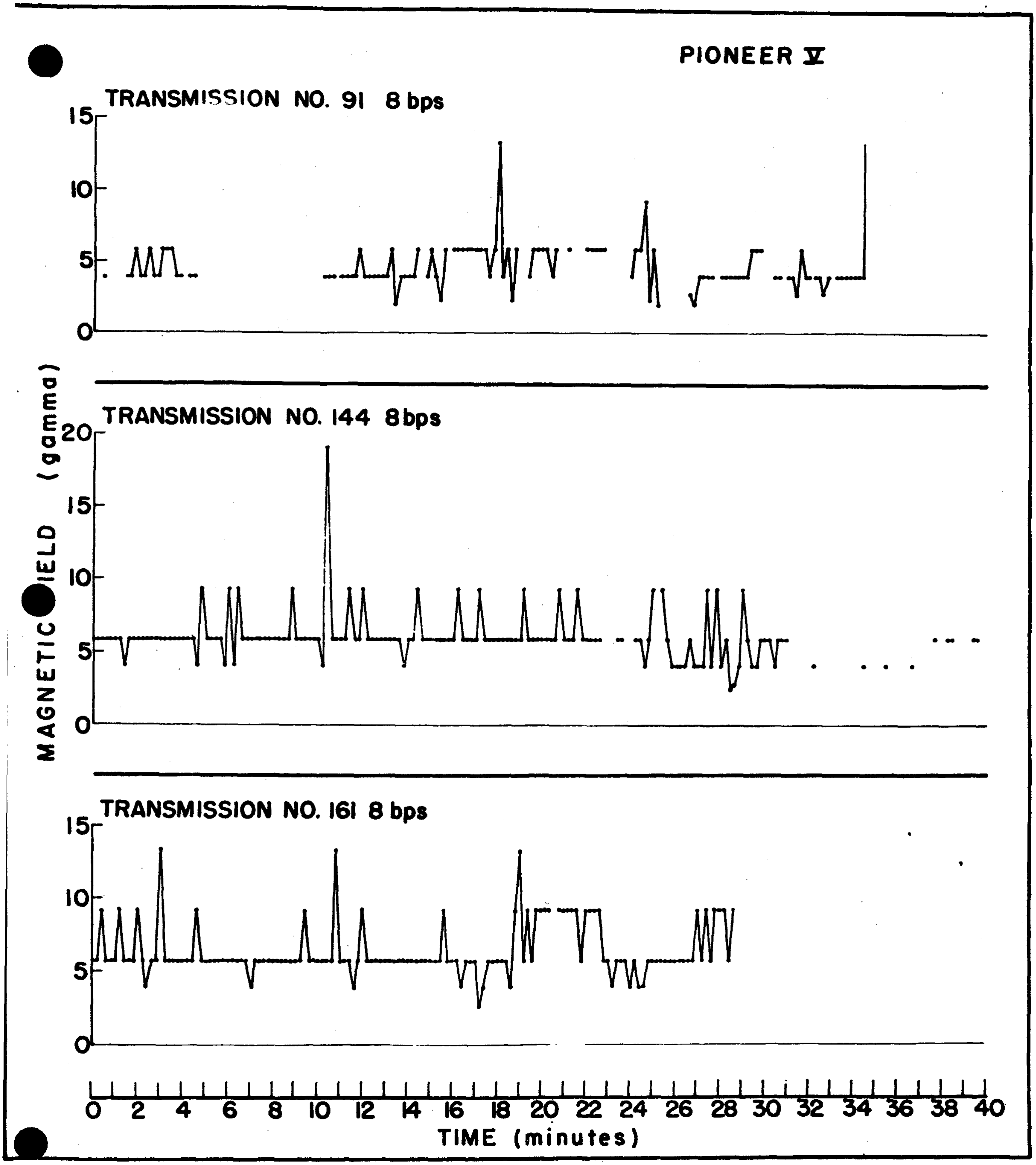

PIONEER V
TRANSMISSION NO. 91 8 bps
TRANSMISSION NO. 144 8 bps
TRANSMISSION NO. 161 8 bps
MAGNETIC FIELD (gamma)
TIME (minutes)
0
5
10
15
20
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

FIGURE 10

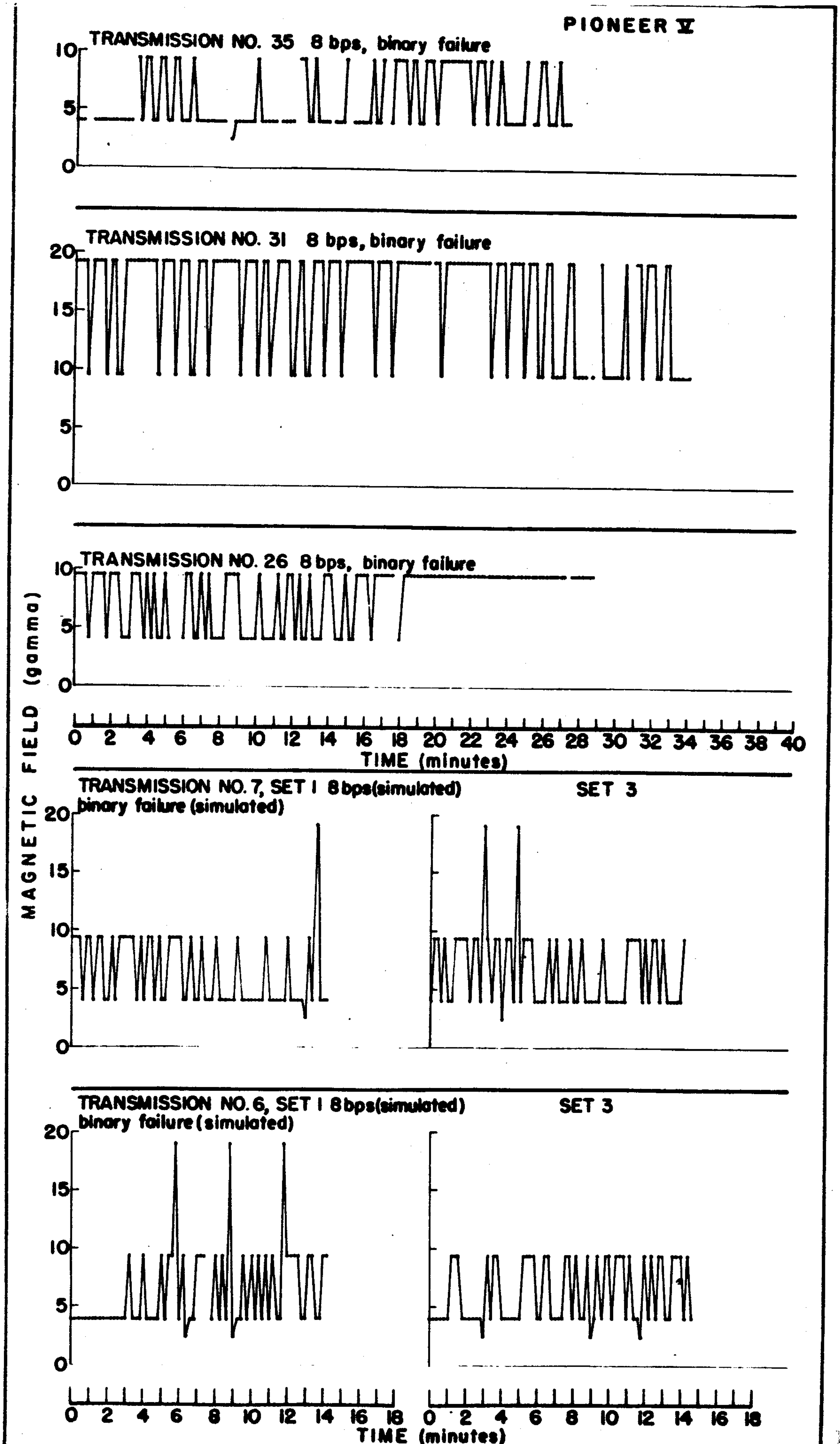
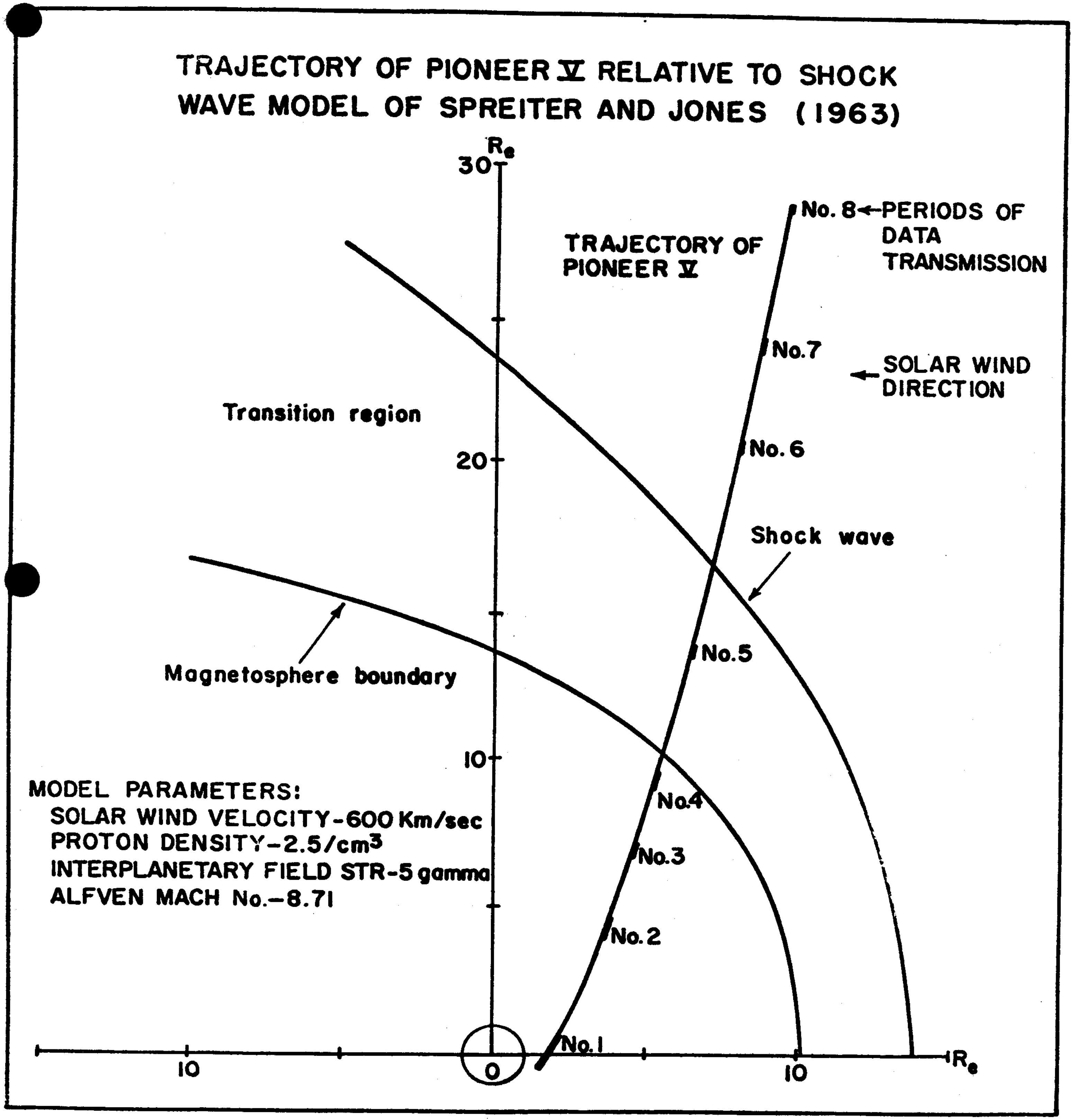
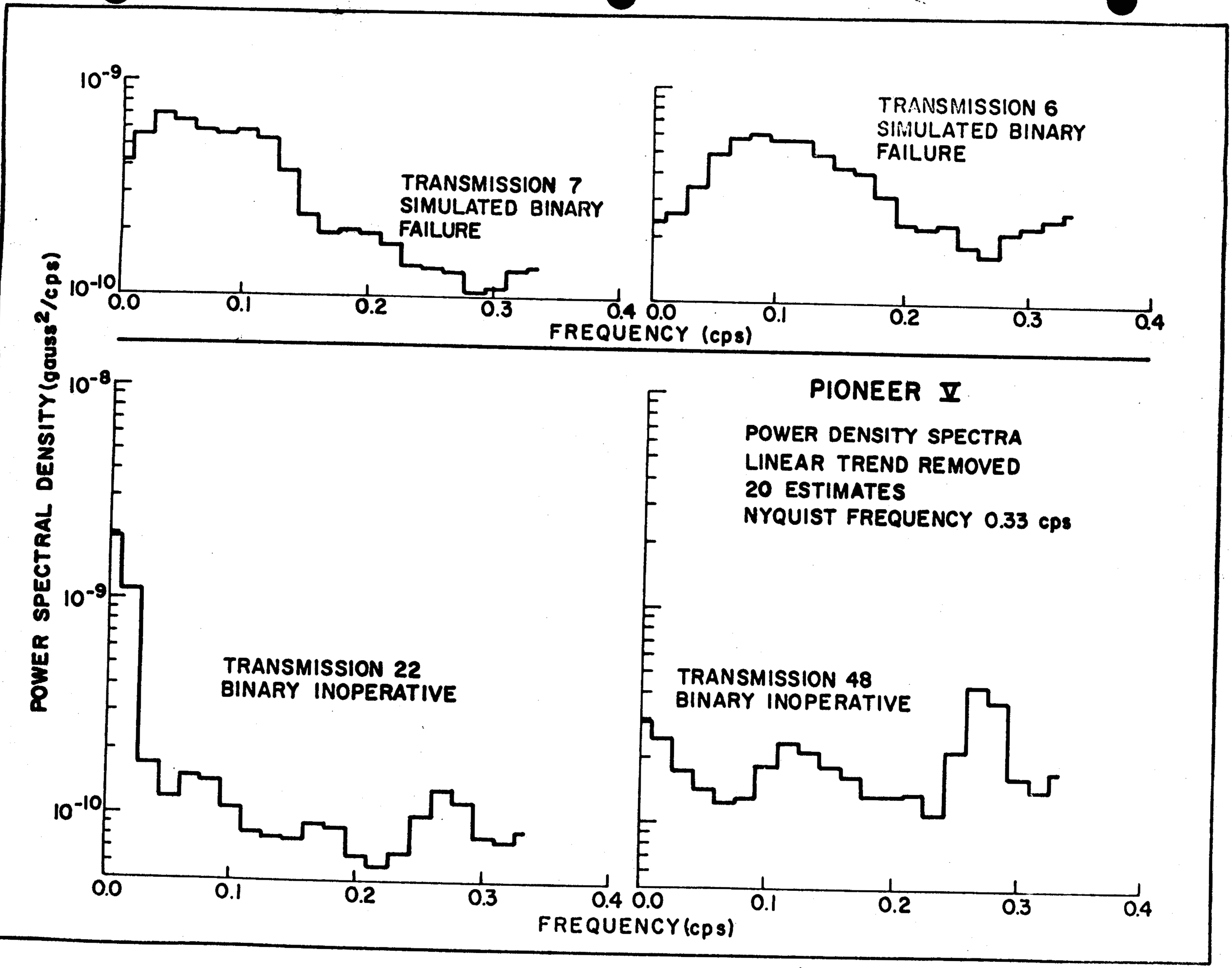

PIONEER V
TRANSMISSION NO. 35 8 bps, binary failure
TRANSMISSION NO. 31 8 bps, binary failure
TRANSMISSION NO. 26 8 bps, binary failure
MAGNETIC FIELD (gamma)
TIME (minutes)
TRANSMISSION NO. 7, SET I 8 bps(simulated)
binary failure (simulated)
SET 3
TRANSMISSION NO. 6, SET I 8 bps(simulated)
binary failure (simulated)
SET 3
TIME (minutes)

FIGURE 11


TRAJECTORY OF PIONEER V RELATIVE TO SHOCK WAVE MODEL OF SPREITER AND JONES (1963)
R_e
30
20
10
0
10
10
R_e
No. 8 ← PERIODS OF DATA TRANSMISSION
TRAJECTORY OF PIONEER V
No.7
SOLAR WIND DIRECTION
Transition region
No. 6
Shock wave
No.5
Magnetosphere boundary
No.4
No.3
No.2
No.1
MODEL PARAMETERS:
SOLAR WIND VELOCITY-600 Km/sec
PROTON DENSITY-2.5/cm^3
INTERPLANETARY FIELD STR-5 gamma
ALFVEN MACH No.-8.71



PIONEER V
POWER DENSITY SPECTRA
LINEAR TREND REMOVED
20 ESTIMATES
NYQUIST FREQUENCY 0.33 cps
POWER SPECTRAL DENSITY (gauss²/cps)
FREQUENCY (cps)
TRANSMISSION 7
SIMULATED BINARY
FAILURE
TRANSMISSION 6
SIMULATED BINARY
FAILURE
TRANSMISSION 22
BINARY INOPERATIVE
TRANSMISSION 48
BINARY INOPERATIVE

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